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FRUITING AND SHEDDING OF COTTON IN RELATION TO LIGHT AND OTHER LIMITING FACTORS

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Cotton plants become well-fruited under conditions that favor the production of a large number of blooms, little shedding and moderate vegetative growth. The studies reported in this bulletin show that adequate sunlight is an important factor in these conditions.

Variations in the amount of light, such as accompany periods of cloudy weather, short days, and close spacing of plants, were found to result in impairment of fruiting and excessive vegetative growth. The heavy shedding of young bolls often noted by growers following periods of rainy weather is probably due to the interruption in high sunlight intensity rather than to the direct effect of rain on the flower.

Modified light conditions and other factors that induce shedding have been found to hinder photosynthesis and to reduce the carbohydrate content in cotton leaves.

Differences in the sensitiveness of cotton varieties to unfavorable light conditions indicate the importance of careful selection of varieties for a given region, according to prevailing weather conditions during the fruiting season, and the need for attention to these inherent varietal differences by the cotton breeder.

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FRUITING AND SHEDDING OF COTTON IN RELATION TO LIGHT AND OTHER LIMITING FACTORS

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Cotton is considered a sun-loving plant, although the importance of adequate sunlight in the production of cotton is not clearly understood. In addition to the water and temperature requirements, Canney (11) has listed abundant sunshine as a third dominant factor essential for high yields of this crop and he has shown that the well established cotton fields of the world lie within the belts of "minimum cloud zones", namely, between 10° and 35° N and 12° and 35° S latitudes. Even within the American cotton belt, Canney has pointed out certain areas, including the coastal plain from New Orleans to Galveston, that have too little sunshine for profitable cotton culture. Regions of "half cloudiness" annually are designated as having too little sunshine, while "three-fifths cloudiness" is extremely unsuitable for cotton. Although specific responses of the cotton plant to poor light conditions are not described by Canney, it is reasonable to presume that stimulated vegetative growth, decreased flower-bud formation, and increases in rates of shedding might result as coincident physiological disturbances.

For many years, probably ever since the crop has been cultivated for commercial purposes, the shedding of young cotton bolls and immature flower buds has been a matter of concern to cotton growers. In 1899, Earle (20) mentioned shedding of bolls along with the diseases of cotton in Alabama, and stated that it was a physiological trouble that often caused considerable loss. Although heavily-fruited cotton plants with but few scars where bolls have been shed are often found in the field, it is considered more or less normal for the cotton plant at time of maturity to have shed from 20 to 50 percent of its immature fruits. Excessive shedding, frequently amounting to 80 percent or more of the fruiting forms and often commencing soon after the first bolls start to develop, may cause noticeable losses in cotton yields. High shedding rates are frequently associated with favorable moisture and fertility conditions which result in close stands of large plants. Lower shedding rates are usually associated with cotton plants that have attained only a small or medium size due to low soil moisture or fertility.

A review of certain studies involving the yields of cotton in the same area in different years brings out the fact that high rainfall during the growing season is frequently accompanied by low yields of cotton. For example, data taken by McDowell (40, 41) at the Iowa Park substation, under irrigated conditions, from 1932 to 1942 show that those years during which the highest rainfalls were recorded were not the ones in which the best yields of cotton were made. In the Iowa Park area, boll-weevil damage was not an important variable factor in the different seasons. Likewise Reinhard (44) reporting 14 years' work at College Station, where boll-weevil damage is common, presented data which show that the poorest yields of cotton were obtained during the years which had the highest rainfall during May, June, and July (1929, 1936, and 1940). After making correction for boll-weevil damage, Johnson and Wadleigh (32) showed that the yields of cotton in Arkansas in 1919, 1923, and 1930, when there was high rainfall in May, June, and July, were on the average one-third less than those of 1926, 1931, and 1934, when the rainfall for the same months was only two-thirds that of the low-yield years. These writers state that rainfall of from 3 to 6 inches during July appeared most favorable for high yields of cotton and that monthly precipitations "above 6 inches in the summer months correspond to markedly decreased yields." Carver (12), working in Florida, states that there is "a general tendency for low yields in rainy years and high yields in dry years." Although variations in many factors as well as light are associated with variations in rainfall, it is possible that the increase in number of cloudy days during months with high rainfall may be, at least in part, responsible for these unfavorable effects of rainy seasons on yields of cotton. Under such conditions, a part of the reduction that may occur in the amount of fruit set on the plants may be due to increased rates of normal shedding.

Fruiting tendencies in cotton that are commonly observed under field conditions indicate the importance of sufficient sunlight and suitable moisture conditions in maintaining high yields. Cotton growers often note excessive shedding of young bolls following periods of rainy weather or showers. When the first bolls are nearing full size, they often make the remark that a good yield would be obtained with the amount of moisture already present in the soil, if clear weather could be had for the remainder of the fruiting period. Unfavorable cloudy weather during critical periods may often be encountered in such regions as the lower Gulf Coast, in the Corpus Christi area for example, where the cotton is planted relatively early in the season and where cloudy or rainy weather may be expected each year about the time the first bolls are developing in late May and June. On June 19, 1945, examination of shedded forms gathered from beneath cotton plants in an irrigated field selected at random near Mission, Texas, showed 72 percent of the shedding to be "normal" and consisted of small bolls a few days after flowering. In this field the plants were in an actively growing condition about 30 inches tall with from 6 to 10 good sized bolls per plant and each plant had shed from 5 to 12 forms mostly from the lower fruiting branches. The plants were closely spaced and shaded one another in the usual manner. Large plants with relatively few bolls, frequently occurring under Lower Rio Grande Valley irrigated conditions, may result from the shedding of non-injured, young bolls during the early fruiting stages. If this early shedding could be prevented, smaller plants with much larger numbers of bolls might be obtained.

At College Station on July 28, 1945, counts of shed forms gathered beneath cotton planted on April 17 showed 55 percent of the shedding to be normal and the remainder to be boll weevil and bollworm damage. This field had previously received three applications of calcium arsenate dust, on July 5, 11, and 20. The plants in this case were about three feet tall, in a close stand and only the oldest bolls had reached full size.

On another occasion in northwest Texas (near Aspermont, Stonewall county), a field in which the cotton plants were about 2 feet tall was observed on August 10, 1943, after a period of dry weather. The plants at this time showed wilting symptoms early in the day. Only a few of the plants in this field had bolls that were past the shedding stage, yet over half of the fruiting forms, including the squares of various ages as well as the young bolls, had been shed. No boll-weevil damage was found in this field. These observations indicate that similar relatively heavy and premature shedding of cotton may occur frequently in certain areas and under certain growing conditions.

Accurate estimates of crop losses from shedding in cotton are not readily obtained. It is also difficult to estimate the depreciation in yield from generally poor fruiting activities as a result of unfavorable environmental conditions. However, the general awareness of the cotton farmer to losses from shedding and the large number of scientific investigations that have been made of the problem indicate that the phenomenon is of prime importance in cotton production. Prescott (43) states that "the low yield in 1916-17 was associated with excessive shedding, boll disease and insect attack," in connection with cotton experiments in Egypt. After working for several years in Mississippi on the shedding problem, Ewing (23) has made the following statement: "From these figures it is evident that shedding must influence the yield of cotton and is to be taken into account in any analysis of the fruiting process." The necessity in some areas of producing an early crop of cotton may also make low shedding rates important in the attainment of good yields. For example, before the invasion of Egypt by the pink boll worm, young cotton plants were kept dry so as to force root development in preparation for a heavy late crop. This practice, according to Templeton (51), caused considerable shedding of squares, a result that was overlooked. With the danger from the boll worm, however, the growers now water the plants to prevent early shedding and to obtain the largest early crop possible.

Many reasons have been given for "normal" shedding of cotton forms, among which the most frequently stated causes are drought, high temperatures, load of fruit on the plant, fluctuations in environmental conditions, and incomplete fertilization of the flowers.

Causes for shedding as given most frequently in the literature include insufficient soil moisture (1, 7, 23, 30, 38), and high temperature (7, 27, 38, 50). In addition, the presence of too much water in the soil or a high water table (2, 7, 34, 43) and daytime rain (38) have been mentioned as predisposing factors to shedding in cotton. In many cases sudden changes in certain, often unspecified, environmental conditions have been emphasized as important considerations in this problem. For example, Berkley (9) found that cotton plants grown under a long day length (12 to 24 hours) shed all of their squares when placed under 8 hours of light per day. These causes are distinct from the several different types of injury due to insect or fungous attack that are recognized as common factors in shedding and which do not constitute "normal shedding." Speaking of conditions within the cotton plant, Mason (39) summarizes as follows: "The general conclusion was drawn that the proportion of shedding over any given period was the resultant of two opposing factors, the rate at which food was synthesized by the plant and the rate at which it was utilized in the maturation of the fruit; and that any check in the former augmented the rate of shedding."

In a few cases, research workers have noted possible correlation between periods of cloudy or rainy weather and high rates of shedding occurring a few days later. In writing of his work with Sea Island cotton in the West Indies, Mason (39) states that, during the later stages of the plant's growth, dark rainy days were "the invariable precursors of augmented rates of boll-shedding." In Arizona, King and Loomis (35) noted heavy shedding of Acala cotton during rainy seasons. According to Thornton (52), the "small amount of sunshine" and high humidity appeared responsible for shedding during the wet season in Nigeria. It was also noted by Thornton that shedding during the wet period was not uniform but was higher on certain days following cloudy or rainy weather with high humidity. The following statement by Ewing (23) is of further interest: "In some seasons it is quite possible that lack of sunshine during protracted cloudy weather may be detrimental to the cotton crop, quite apart from the other conditions which accompany such weather." Lloyd (38) made a detailed study of boll-shedding in Alabama and noted a tendency for higher rates of shedding to follow a few days after daytime rains. The partial explanation was advanced by Lloyd that rain prevented normal fertilization in the cotton flower, but he also states that "the shedding of bolls older than 8 or 9 days and which are therefore probably past the danger from imperfect fertilization, can be caused experimentally to shed in as short a period as younger bolls and large squares." Mason (39) has stated that "destruction of pollen by rain was responsible for a small proportion of the shedding." Apparently no attempt was made by Lloyd or other workers to associate increased rates of shedding following rain with impaired light conditions during the rainy weather. However, in discussing the effects of heavy rainfall on shedding, Earle (20) has stated that "the continued dark, cloudy weather would interfere with the normal action of the leaves."

Differences among types and varieties of cotton in regard to rates of shedding have been noted many times by different investigators. Kearney and Peebles (33) have shown that differences in shedding rates are inheritable in crosses of Pima and Acala strains. Beckett and Hubbard (8) found that 4-lock bolls tend to shed less readily than 5-lock bolls, in the case of Lone Star and Acala varieties, although environmental conditions may affect the relative susceptibility to shedding of these two types of bolls.

Few comparisons of cotton varieties in regard to their shedding tendencies in response to unfavorable environmental conditions have been found in the literature. In the words of Balls, "the cotton plant in Egypt is the slave of environmental circumstances which permit to it but little display of individuality in the matter of its yield, and the conjecture made by the author in 1910, that the causes of yield deterioration should be sought in the environment and not in varietal deterioration, seems to be fully justified." It is well known that some varieties tend to shed a larger percentage of their forms than other strains and Ewing (23) has reported differences in shedding rates among certain varieties of cotton in Mississippi. Egyptian varieties were observed by Kearney and Peterson (34) to show drought effects sooner than upland varieties. In a comparison of certain varieties under the dry-soil conditions in East Texas, Young (56) noted apparent drought resistance and relatively little shedding of foliage by the Dixie Triumph W. R. Str. 21 cotton. In Arizona, Hawkins (28) found that Acala suffered more than Pima from drought, as shown by heavier shedding of young bolls from the Acala plants. Also, under Arizona conditions, King and Loomis (35) noted that the Acala variety showed a higher shedding rate than Pima during the last three weeks in July, 1926 when there was heavy rainfall and plant growth was rapid. Correlation between the daily shedding of young bolls of Acala cotton and osmotic pressures of expressed leaf fluids was found by Hawkins et al. (29), although this correlation did not hold for the Pima variety. There was somewhat better correlation between holl shedding and the concentration of boll fluid than with the osmotic pressure of the leaves.

As in the case of shedding, relatively few reports have been found in the literature pertaining to the effects of light on vegetative growth and general fruiting processes in the cotton plant. In regard to the influence of day length, Berkley (9) found fruiting to occur in cotton under conditions of an 8-hour day, or longer, provided suitable temperature and other conditions were maintained. In regard to the effects of varying light intensity, Shantz (47) noted that cotton made the best growth at 1/5 to 1/2 normal light and no great reduction in growth was noted at 1/15 of normal light. No data on fruiting were reported by Shantz. In discussing the effects of day length on different species of cotton, Konstantinov (37) states: "The conclusion to be drawn from what has been stated here is that all cottons are not characterized by the same sensitivity to light." However, few of Konstantinov's findings are concerned with differences in fruiting capacities of upland American cotton varieties. As a result of shading experiments during two years in Northern Sudan with Delrect

II, an American variety of cotton, Knight (36) concluded: "After making due allowance for differences in diseases and pests, the results obtained in both seasons show clearly that partial shading (and hence, presumably, any prolonged heavy cloud-effect) greatly reduces the yield of cotton, largely by a direct effect on the growth of the plants, though partly through an increased pest incidence," and that "continued cloudiness may be a major factor in lowering the yield of cotton." In this work, Knight found that continuous shade with coarse white cloth reduced the yield by nearly two-thirds, although the amount of shedding was less on the shaded plants, due to production of fewer blooms under the shade. Novikov (42), working with potted cotton plants in Russia, found that lowering the light intensity by shading to 21 percent of full sunlight resulted in greatly increased vegetative growth, although the best yield of cotton was obtained under full-sunlight conditions. A study of Stoneville 2B cotton, including data on fruiting processes, has been reported by Eaton and Rigler (22) with plants grown under white-cloth shade in the greenhouse during the winter in comparison with outdoor plants in full sunlight in the summer. Temperature studies in relation to the growth of cotton have been made by Balls (7) and by Berkley and Berkley (10), although little work has been reported concerning the effects of high temperatures on fruiting processes in the plant. Many reports of the effects of drought conditions on growth and fruiting in cotton have been published (1, 23, 27, 28, 30, 40, 41, 43, 51, and others).

It has been the primary purpose of this research to ascertain the importance of light effects, especially periods of low light intensity, among the factors that influence fruiting in the cotton plant. In addition, an attempt has been made to evaluate these light effects in comparison with other factors such as variations in water supply and high temperatures. A few studies on cotton fruiting involving variations in nitrogen and certain mineral elements have been included in this work. Varietal differences among upland cottons have been studied in relation to sensitivity to such unfavorable changes in light intensity as might be caused by cloudy weather. All of these studies have involved the taking of data under a wide variety of environmental conditions at College Station, over a 6-year period from 1939 to 1945. A few preliminary reports of this work have been published previously (16, 17, 18).

METHODS AND PROCEDURE

The conditions and methods applicable in general to broad aspects of the work are stated in this section. In many instances, however, details of experimental conditions, materials, and procedure are given along with the presentation of data under subsequent headings.

Definition of Terms

Shedding is used to designate the dropping of bolls or squares by formation of an abscission layer near the base of the stalk. Unless otherwise designated, the term is used here to indicate *normal shedding* which refers to abscission due to purely physiological causes and does not include shedding due to insect, fungus, or mechanical damage.

The flower buds up to the time of flowering are designated as *squares;* after flowering the developing cotton fruit is called a *boll. Bolls* are designated as *young* or *old* depending upon the time that has elapsed after flowering. The term *form,* or *fruiting form,* is used to designate a fruiting structure in either the square, flower, or boll stage (see fig. 1).

In this work, *fruiting period* is used to designate that period in the life of the plant beginning with the opening of the first flower and extending up to the opening of the first bolls (*time of harvest* in this work).

Percent set is the ratio obtained by dividing the number of bolls maintained past the shedding stage by the number of blooms.

Fruiting index is obtained as a ratio of the weight of green bolls to the fresh weight of leaves and stem, at time of harvest (opening of first bolls); this index could be used to show the amount of plant growth necessary to produce a boll.

The Experimentation

Varieties. During the first two years of this work the Startex variety of cotton was used in the preliminary experiments. Later, the Rogers

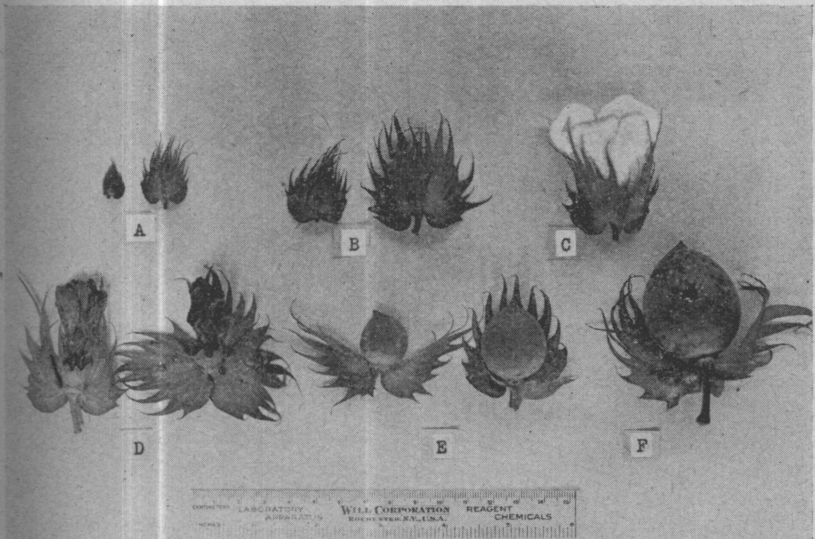


Fig. 1. Various ages of cotton fruiting forms: A. Small squares; B. Large squares; C. Bloom; D. Small bolls a few days after blossoming; E. Bolls about 1/4 to 1/2 grown; F. Boll approaching full size and too old to be shed readily. The bloom opens about 20 days after the square becomes large enough to be seen; young bolls reach full size in about 2 weeks but from 6 to 10 weeks are required after blossoming before the boll is ripe enough to open. Under ordinary conditions, most of the shedding takes place just after blossoming (D).

Acala No. 111 variety was used in several experiments and this was followed with Stoneville 2B as the main variety. Since considerable variation was found among the above varieties in their reactions to differences in environmental conditions, a group of varieties was suggested by Mr. D. T. Killough, agronomist, for comparative study. These were: Stoneville 2B, Rogers Acala No. 111, A. D. Mebane Estate, Deltapine 14, Roldo Rowden, Qualla, Coker 4-in-1, Washington (Delfos), Lone Star, and Half and Half. In addition, a few plants of Dixie Triumph, Miller 610, Sunshine Rowden, and Watson were used in a few instances.

Source of seed. Certified seed of the various varieties was in nearly every case obtained directly from the seed grower through Mr. Killough and in most cases the grower was the originator of the variety.

Culture. Two types of culture were used—*soil* and *sand*. The soil consisted of a mixture of approximately 3 parts sandy loam, 1 part rotted manure and 1 part granulated peat moss. In most cases, additional chemical fertilizer treatments were added after the plants had begun to set fruit, consisting of measured amounts of dry nutrient chemicals (for 4 gal. of soil—usually about 10 g. $(NH_4)_2SO_4$, 5 g. of KH_2PO_4, and 2 g. $MgSO_4$ were added to the soil surface). Unless otherwise stated, the soil was watered frequently enough to prevent wilting for more than a brief period. Usually the soil was allowed to become fairly dry, almost to the wilting point before a sufficient quantity of water was added to moisten the soil to near the bottom of the container.

With sand culture, the plants were grown in washed river or creek sand with nutrients supplied in solution. The river sand was reddish brown in color and usually gave an alkaline reaction around pH 8. The gray creek sand was slightly acid to neutral (pH 6-7). Tests with acid showed the river sand to contain many carbonate particles. The cotton seeds were planted directly in the moist sand and given nutrient solution after emergence. As soon as the plants showed several small squares they were given each day about 1 liter of a nutrient solution of the following approximate composition: 90 p.p.m. N, supplied as NH_4NO_3; 40 p.p.m. K and 32 p.p.m. P supplied as KH_2PO_4; 5 p.p.m. Mg as $MgSO_4$; 3 p.p.m. Ca as $Ca(NO_3)_2$, 4 p.p.m. B as H_3BO_3; and a trace of Mn as $MnSO_4$. The acidity of the final solution was adjusted to about pH 5.0-5.5 with sulphuric acid. Commercial grades of nutrient salts, when available, and tap water were used in making the nutrient solution. In addition to the daily applications of the nutrient solution the plants were given tap water whenever necessary to prevent wilting. Tests of the pH of the sand after the plants had grown to maturity indicated that the substrate in the case of the brown river sand remained near 7.0 pH while the gray creek sand varied from 4.8 to 6.0 pH. Good growth of the plants was obtained with both types of sand, and no consistent differences in any of the results of the experiments appeared that were attributable to differences in the substrates. In general, the results obtained with soil cultures closely paralleled those with sand. As a rule, the sand-culture plants continued to grow for a longer period than comparable plants in soil and they were somewhat later in reaching a dormant condition following a heavy set of fruit.

The containers in which the cotton plants were grown consisted for the most part of glazed jars with a drainage hole in the bottom. For soil culture, 4-gal. jars were used most frequently, with certain experiments involving 1-, 2-, 3-, and 5-gal. jars. With sand, 2-gal. jars were commonly used, although certain phases of the work were done with plants in 7-inch varnished flower pots, as well as 1-gal., 3-gal., and 4-gal. jars. Except in certain special cases, a single plant was grown in each container. The jars were normally spaced so that the stems of the plants at the soil surface were from 20 to 24 inches apart.

In general, four series of plants were raised during a 12-months period. The first series (spring) was planted in January and harvested in May. This was followed by an early-summer series planted in April and harvested in July. A late-summer series was planted in June or July and harvested in September or October. The fourth series (usually referred to as the *fall*, or *fall-winter*, series) was planted in September or October and harvested in December or January. The spring and fall series were raised entirely under greenhouse conditions. The early summer series was started in the greenhouse and the plants placed outdoors during May, while the late summer series was raised entirely outdoors.

Insect control, when needed, was obtained outdoors by dusting the plants at regular intervals with calcium arsenate for boll weevils and spraying with nicotine sulphate for cotton aphids. In the greenhouse, aphids were controlled by fumigating with "Nicofume Pressure Fumigant"; tartar emetic and brown sugar solution was used against thrips; and the houses were fumigated with "Cyanogas" for control of white flies and leafhoppers.

Temperature and humidity. Records were made with a Friez Hythergraph of the temperature and humidity under the conditions of the experiments at different times of the year. Fig. 2 shows representative temperature records for greenhouse conditions in the winter and spring and for outdoor conditions in the summer. Under greenhouse conditions, with the thermostat set at 85° F., the average maximum temperature during the late fall and winter months (November to January, incl.) varied from around 88°-93° on clear days, and the minimum night temperatures varied from 65° to 85°. The relative humidity in the greenhouse for this period remained between 40 to 60 percent most of the time, with frequent periods of 70 to 90 percent and infrequently as low as 20 to 30 percent. During the spring series (March to May, incl.) the average maximum temperature in the greenhouse was somewhat higher (around 92°-95°) on clear days, than in the fall. The relative humidity records show little difference between the fall and spring months in the greenhouse. During the summer outdoors, the usual maximum temperatures on clear days varied around

90°-96° F., and at night the temperature varied from 74°-80° F. In some years, certain periods had considerably higher maximum daily temperatures than in other seasons. Extremes in weather conditions caused occasional, brief periods of temperature conditions considerably beyond the limits of the averages given above. The relative humidity outdoors in the summer varied from 25-35 percent on clear days to around 70-90 percent at night.

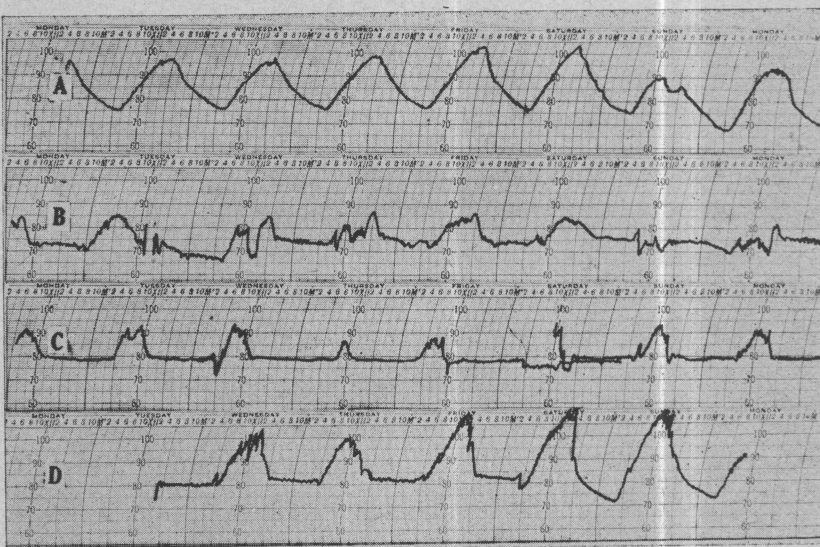


Fig. 2. Weekly temperature records that represent conditions in connection with these experiments at different seasons of the year. A. Outdoors in shade of shrubbery, August 13 to 21, 1945. B. On greenhouse bench, March 28 to April 4, 1944. C. On greenhouse bench, November 16 to 25, 1940. D. Under greenhouse bench, May 20 to 26, 1941. Note the taller and much broader peaks in the summer curve (A) than in the fall or springs curves (B and C).

Variations in light. The cotton plants grown at different seasons of the year were subjected to distinct differences in light intensity and length of day. For example, the light intensity measured with a Weston Model 603 Illumination Meter on clear days at noon in midsummer was around 14,000 foot candles while similar outdoor readings in December showed only about 8500 f.c. Likewise, the length of day (period between sunrise and sunset) varied from about 14 hours in June to about 10 hours in December. In addition to these seasonal variations, the average percentage of cloudy days as recorded at the Main Station Farm, College Station, over a five-year period (1939-1943) was 30 percent for April and May, 26 percent for July and August, and 43 percent for November and December.

Light intensity on both clear and cloudy days was measured on several occasions at different seasons of the year. Since much of the experimental work involved varying the light intensity by shading the plants, several of the readings taken under different weather conditions are listed in table 1. These readings were taken near the greenhouse with the target of the Weston meter directed towards the zenith. Within the greenhouse the light intensity was usually 15 to 30 percent less than the intensity outdoors.

Experimentally, differences in light intensity were obtained by placing the plants indoors, by shading with cloth or slat shades, or by varying the spacing between potted plants. Black cloth which reduced the light from 90 to 98 percent was most frequently used. Some white cloth shades were also used, which reduced the light intensity about 70 to 80 percent. In every case, the shades were placed over the plants in such a manner as to allow free circulation of air from the outside. Even under conditions of bright summer sunshine, the differences in temperature between the outside and inside of the shaded enclosures were not more than a few degrees F. The shading effects of cotton foliage were also studied by spacing plants close together (about 12 inches between stems) in comparison with plants spaced farther apart (about 22 inches between plants). In certain other experiments involving length of day or number of hours per day of direct sunshine, a light-impervious airplane fabric* was used for shading during definite periods each day.

Variations in soil moisture and temperature. In the experiments with wilting, low soil moisture conditions were obtained by one of two methods: (1) Maintaining the plants at or near the wilting point for definite periods by frequent light waterings and (2) Daily weighing of the plant in container and adjusting to a definite weight each day by the addition of water. Intermittent periods of water-stress were obtained by allowing the plants to remain wilted for a certain period before each watering.

Certain differences in temperature occurred in the growing conditions at different seasons of the year, as shown in fig. 2. For studying the effects of higher-than-normal temperatures, the plants were kept in an unshaded greenhouse during the summer or in a closed or partially ventilated greenhouse at other times of the year. In one case studies of the effects of low temperature were made in a non-heated greenhouse in the winter.

Taking of data. In many of the experiments, records were taken at intervals of one, two, or three days of the number of bolls (and squares) shed from each plant. Occasional bolls or squares that showed injury, due to insects or other causes, were not included in the data. Final records were taken at time of harvest of the plants, when the first bolls started to open. By the time the first bolls were opening the outdoor plants of the summer series (soil or sand) had reached a determinate stage of growth, i.e. no new squares were being formed, and the growing points on the main stem and lateral branches were inactive. Under greenhouse conditions, when the first bolls opened, only the most mature soil plants showed

*Grade B airplane fabric "seconds" purchased from Landers Corporation, Toledo, Ohio.

this condition. Sand-culture plants in the greenhouse and soil-plants which had been subjected to different experimental treatments usually had not completely ceased growing when their oldest bolls were open. Measurements in taking of final data included: height of stem from the soil to the main growing point (tip of stem); number of scars where fruiting forms had been shed, number of bolls around 2 cm. in diameter or larger (past the usual size for shedding, fig. 1, F.), fresh weight of these bolls, and fresh weight of above-ground parts of the plant exclusive of the recorded bolls.

Table 1. Light intensity measurements, in foot candles, under various weather and seasonal conditions, at College Station, Texas, 1941-1944

Time of year	Time of day C. S. T.	Weather conditions	Light intensity f. c.
Jan. 27	1:30 P. M.	Clear	8,600
Feb. 11	1:00 P. M.	Clear	10,000
April 11	12:45 P. M.	Clear	12,400
April 24	1:00 P. M.	Clear	12,800
April 24	12:30 P. M.	Dark, rainy	1,100
April 27	1:00 P. M.	Clear	13,200
May 7	1:15 P. M.	Heavy overcast, light areas in sky	1,900
June 26	1:00 P M.	Few drifting clouds	15,000
June 26	2:00 P. M.	Few drifting clouds	12,000
June 27	1:00 P. M.	Large white clouds	16,000
July 6	2:30 P. M.	Just after rain, clearing	2,000
July 10	12:30 P. M.	Few clouds	14,000
July 16	1:30 P. M.	Heavy, broken clouds	14,000
July 29	12:00 N.	Raining	400
Aug. 16	12:30 P. M.	Mostly clear, cloud over sun	2,500
Aug. 17	12:00 N.	Hazy atmosphere; shadow barely visible	6,000
Aug. 22	12:00 N.	Cloudy, just before shower	1,400
Aug. 27	12:30 P. M.	Raining	820
Aug. 28	1:00 P. M.	Shower	220
Aug. 29	12:30 P. M.	Light overcast, scattered showers	2,500
Sept. 7	12:30 P. M.	Cloudy, after shower	500
Sept. 15	11:45 A. M.	Overcast	1,400
Sept. 20	12:30 P. M.	Overcast	3,000
Oct. 25	12:45 P. M.	Clear	10,000
Dec. 7	1:15 P. M.	Heavy cloud, just before shower	30
Dec. 14	12:00 N.	Cloudy	680
Dec. 17	1:00 P. M.	Clear	8,400

Analysis of data. Statistical analyses of variance have been made of much of the data presented, as shown by the frequent references to the significance of the differences between the mean values obtained. In some cases (especially in the study of seasonal effects) analyses have been made of the combined sand- and soil-culture data. In these cases, chi-square tests have shown the data to be homogeneous.

LIGHT RELATIONS

The effects of variations in light intensity, day length, and amount of sunlight available to the cotton plant in a given period were studied in several different ways. In this work, the fruiting and vegetative tendencies of different varieties of cotton were compared at different seasons of the year to show the effects of environmental differences in light and temperature. Experimentally, low light conditions were provided by shading the plants with cloth or by placing them in a shaded greenhouse or laboratory room. Close spacing of containers with cotton plants was also a means of providing low-light-intensity conditions for the experimental plants without changing other environmental conditions appreciably. When closely spaced the leaves of neighboring plants intermingled and shaded one another. The effects of brief periods of shade and of longer periods of low light intensity were both studied in relation to shedding and fruiting tendencies. In addition to variations in day length encountered under the different seasonal conditions mentioned above, the effect of the length of the daily period during which cotton plants were exposed to the direct sunlight was studied by shading the plants for definite periods each day. In many cases, shedding records were taken and examined in connection with the preceding treatments or weather conditions. Wherever varietal differences in response to these variable conditions were found these data are presented following those showing the effect of such conditions on the upland cotton plants in general.

Effects of Cloudy Weather

In many of the experiments conducted from 1939 to 1944, the young bolls that abscised were gathered and recorded separately for each plant, usually at 2- or 3-day intervals, from the time of the first shedding until the oldest bolls had begun to open. From these records graphs have been drawn that show these variations. In addition, the weather records for these same periods have been secured from the meteorological data taken at the Main Station Farm about one mile distant from the site of the experiments. The graphs showing the rates of shedding and the condition of the weather (clear, partly cloudy, or cloudy days) during the same period are combined in figs. 3-6, inclusive.

In examining the graphs showing the effects of cloudiness upon shedding, it should be kept in mind that a certain amount of shedding occurs normally during the fruiting period of the cotton plant. Under uniformly clear weather conditions, a greater portion of the shedding has been found

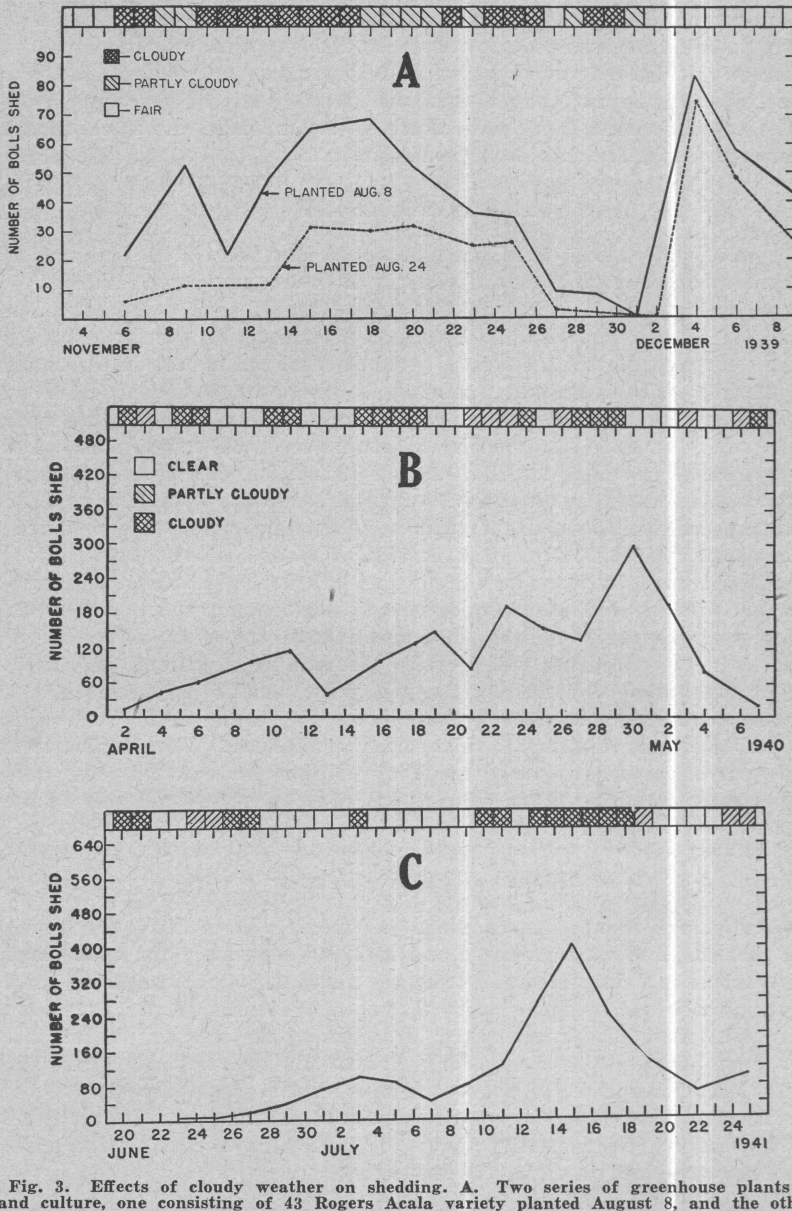


Fig. 3. Effects of cloudy weather on shedding. A. Two series of greenhouse plants in sand culture, one consisting of 43 Rogers Acala variety planted August 8, and the other, 39 plants of Startex variety planted August 24, 1939. Note similarity in shedding curves for the two ages of plants. B. Curve showing shedding record of 106 Startex plants in sand, planted January 13, 1940. C. Outdoor summer series of 112 Rogers Acala plants in sand culture, planted April 10, 1941. Note peak in shedding curve on July 15, associated with overcast sky due to a Gulf storm. The daily weather conditions, as to cloudiness, are shown at the top, in each case.

to occur late in the fruiting period. At times, indeed, no sharp peaks appear in the shedding curve, as may be seen, for example, in the sand plants during the late summer of 1944 (fig. 5, C) and in the behavior of the April 8th planting in 1944 (fig. 19), when light and temperature conditions were relatively favorable and uniform. In most of the graphs (figs. 3-6), one or more distinct peaks are apparent in the shedding curves. In practically every case, the peaks of shedding are preceded by one or more cloudy days that usually occurred two to six days in advance of the shedding response. By mechanically injuring the young bolls, Lloyd (38) found that the time necessary for abscission was six days or less, depending upon the age of the boll and also upon the intensity of the stimulus. As will be indicated in experiments described later, shedding may be expected to occur as early as two days and as late as six or eight days following the initiation of a low-light-intensity period, depending probably upon the condition (amount of sugar and starch reserves) of the plants as well as upon the intensity of the shading. It should also be stated that the designations of cloudy and partly cloudy days as shown in these graphs are more or less arbitrary in that certain days shown as partly cloudy, for example, may have been almost clear while others may have been rather heavily overcast. Likewise, some of the days designated as cloudy may have been only lightly overcast, with a fairly high light intensity for most of the day.

Examination of the shedding curves for the 1939 fall-winter series of cotton plants in the greenhouse (fig. 3-A) shows a high rate of shedding over a prolonged period in November coincident with about eight consecutive cloudy days. Following somewhat less cloudy weather, the curves drop to a low point at the end of November, only to rise sharply again on December 4 during clear weather but following several cloudy days late in November. The shedding curve for the spring series in 1940 (fig. 3-B) shows a trend towards an increase in shedding during May as the plants become older. The four peaks in this curve also correspond more or less regularly with groups of cloudy or partly cloudy days that precede them by short intervals. The single abrupt peak in the curve for early summer plants in 1941 (fig. 3-C) is especially interesting since it occurred in the middle of a week of overcast weather caused by a tropical Gulf storm in July. The other parts of the fruiting period for these plants was accompanied by rather uniformly clear weather and no other shedding peaks occur on the graph.

Again, in the fall series, 1940, three definite peaks occur in the shedding curve (fig. 4-A) following groups of cloudy days as shown by the weather data. Similarly, in fig. 4-B for the fall-winter 1940-41 series and in fig. 4-C for the fall-winter 1943 series, there are three distinct shedding peaks, in each case, which can be associated with cloudiness during the few previous days.

The graph for the 88 Rogers Acala plants in late August and in September 1941 (fig. 5-A) shows a high, sustained rate of shedding from Sep-

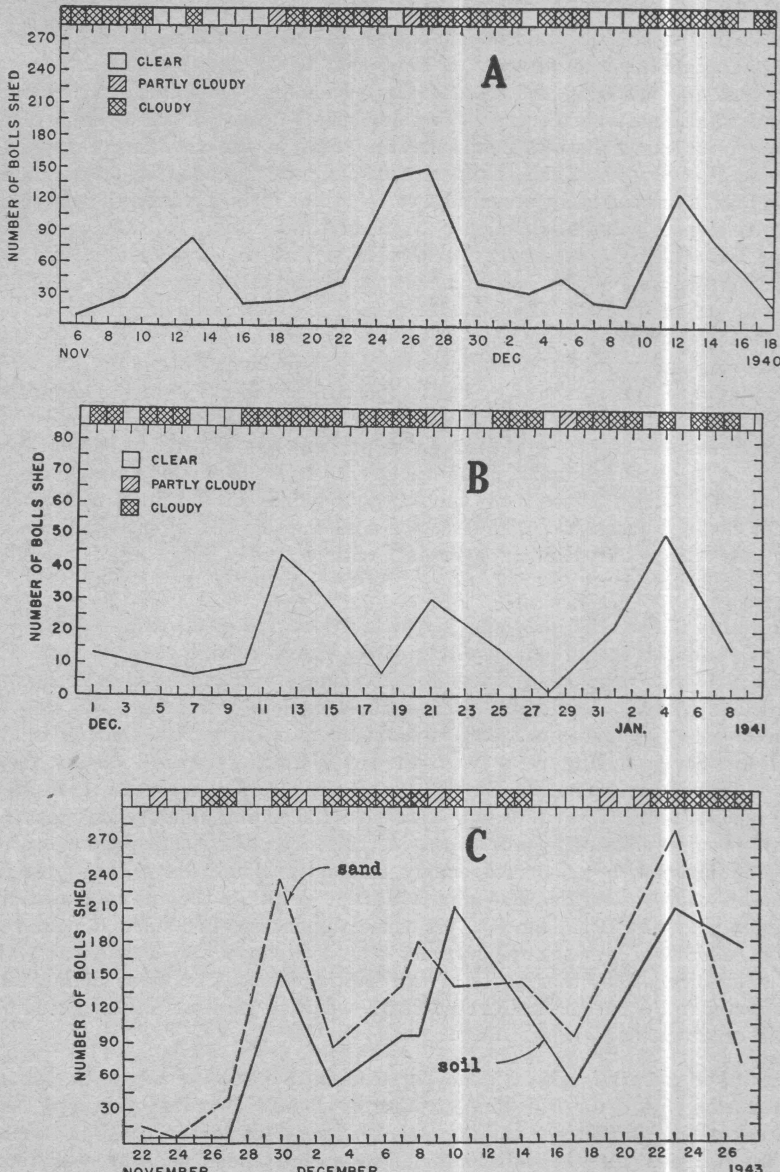


Fig. 4. Effects of cloudy weather on shedding. A. Shedding curve of a fall-winter greenhouse series of 73 Rogers Acala plants in sand culture, planted September 4, 1940. B. Record for 35 Rogers Acala plants in sand culture, planted September 25, 1940. C. Two series of plants—80 in sand and 60 in soil—each series made up of 10 varieties. There was a large percentage of cloudy days in each of the three fruiting periods shown here and shedding was relatively heavy over an extended period in each case.

tember 12 to 18. This broad peak coincides with a period of 10 cloudy or partly cloudy days during the 12-day period from September 7 to 18, inclusive. The shedding record of plants during April and May 1944 shows two distinct peaks (fig. 5-B), one about April 26 following five cloudy days between April 16 and 23 and the second peak about May 3 following another period of several cloudy days. Fig. 5-C shows a marked peak of shedding about September 2, 1944 after a period of twelve consecutive days of cloudy weather. The sand plants in this figure, that matured somewhat later than those in soil, did not show a high peak of shedding in the clear weather during the latter part of their fruiting period.

It is of interest to note the shedding curves of cotton plants of different ages in each of the two graphs, figs. 3-A, 4-C, 5-B, and 5-C. In the first of these graphs (November-December 1939), there is a difference of 16 days in the age of the plants represented in the two curves, and in the third case (fig. 5-B, April-May 1944) one series of plants (broken line) was nearly two weeks older than the other. In fig. 5-C (Aug.-Sept. 1944), the earlier (soil) plants showed an extremely high shedding rate following cloudy weather late in August, and at the same time the later maturing plants (in sand) showed a rate almost as high as at any time during their entire period of fruiting. In spite of differences in age, shedding behavior in the younger plants closely paralleled that of the older plants in each case. Since all of these plants, with the exception of those represented in fig. 5-C, were grown in the greenhouse where uniform, favorable temperatures and soil moisture conditions were maintained, variable sunlight intensity appears as the most likely factor responsible for the close coincidence in peaks of shedding in the young plants in comparison with the older plants. If cotton plants tended to show excessive shedding rates when they reach a certain stage of maturity or fruiting regardless of environmental conditions, it would be expected that the peaks of shedding in the younger plants would occur at a somewhat later date than in the case of the older plants. Such a condition has not been found in these experiments.

After consideration of these shedding graphs (figs. 3, 4, and 5), it seems reasonable to conclude that excessive shedding in cotton is likely to follow unfavorable weather conditions, such as a few to several cloudy days occurring consecutively or close together. These results are based on data taken on nearly 700 individual plants grown at different seasons of the year over a 4-year period. In only one case, under ordinary cultural conditions, has a distinct shedding peak occurred following a period of several days of clear weather and this occurred during a period of unusually high temperature conditions when the plants were in a late fruiting stage (fig. 19).

This conclusion that cloudy weather encourages shedding in cotton is in agreement with observations by both Mason (39) and Lloyd (38). Lloyd's graphs (on pages 89 and 96, l.c.) show that the peaks in the shedding curves for 1912 are due to the probable effects of rain. Furthermore,

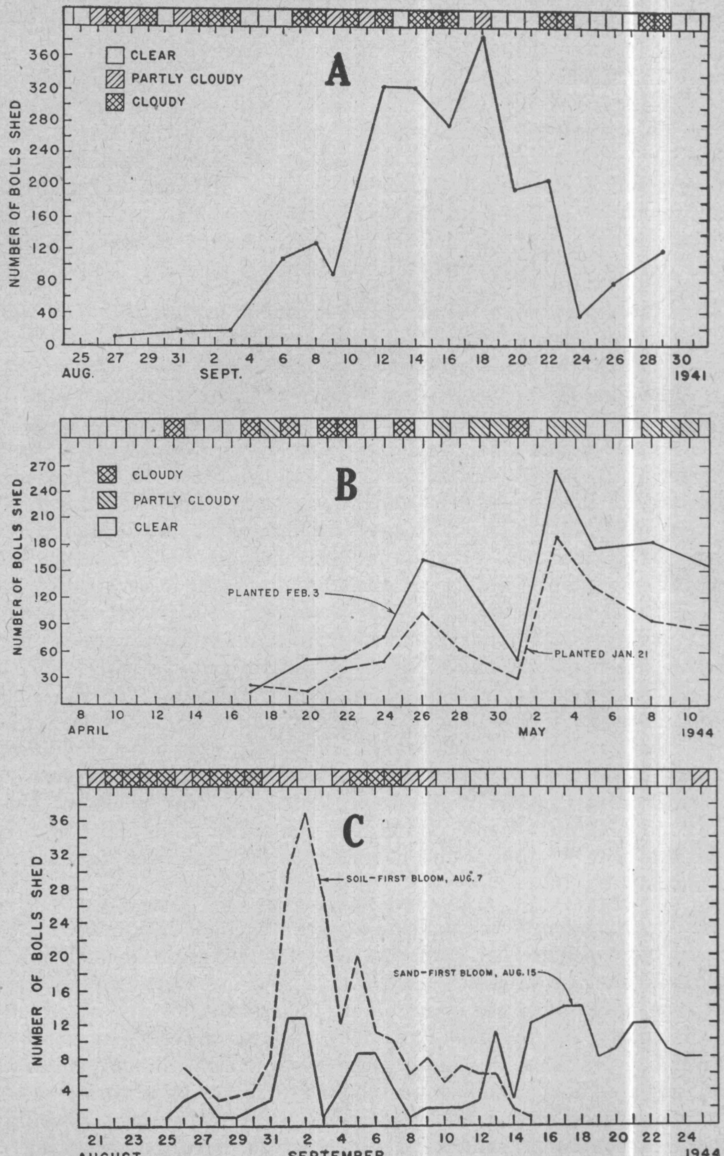
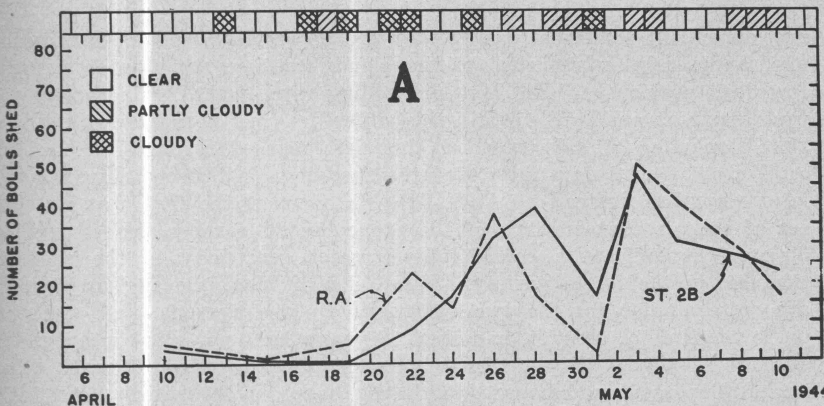


Fig. 5. Effects of cloudy weather on shedding. A. Shedding curve during late summer for 88 Rogers Acala plants in sand culture, planted June 14, 1941. B. Two series of greenhouse plants in the spring—114 plants (broken line) made up of equal numbers of six varieties, planted in 3-gal. jars of soil on January 21 and 64 plants (solid line) of two varieties, planted in 4-gal. jars of soil on February 3, 1944. Note similarity in shedding curves for the two different ages of plants. C. Two series of late summer plants; the 8 plants in 3-gal. jars of soil (broken line) were somewhat earlier than the 11 sand-culture plants (solid line) although both were planted on the same day, June 24, 1944. Note the increased shedding in both groups following a period of cloudy weather late in August.



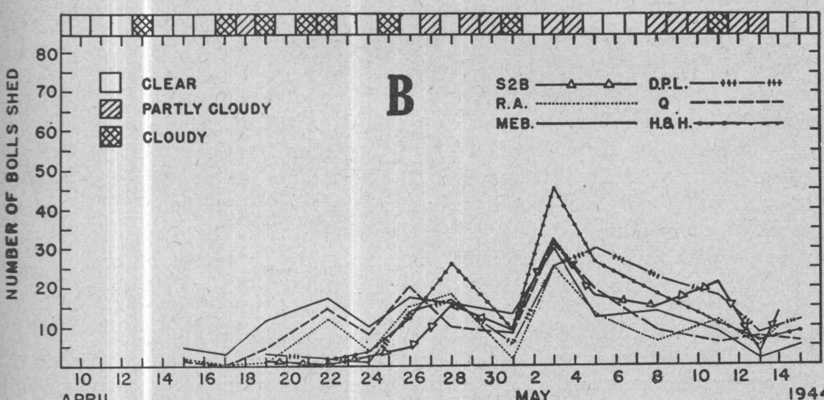


Fig. 6. Varietal differences in shedding responses of cotton to periods of cloudy weather. A. Shedding curves for 16 plants each of Rogers Acala and Stoneville 2B varieties, planted in soil January 21, 1944. B. Similar curves for Stoneville 2B, Rogers Acala, A. D. Mebane Estate, Deltapine 14, Qualla, and Half and Half varieties, planted in soil February 3, 1944. Note the tendency for certain varieties to start shedding more quickly than others following a few cloudy days from April 17-22.

Lloyd shows (graphically on p. 94, l.c.) that the shedding of bolls which were in open flower on rainy days was much more severe than that of bolls from flowers which opened on clear days. The heaviest shedding was also found to take place around the fourth to sixth day after flowering (time of known rain occurrence). These periods of excessive shedding following rainy weather as reported by Lloyd correspond in all major respects with those obtained in this work, even under our greenhouse conditions where rain did not come in contact with the pollen in the open flower. Ewing (23) also noted increased rates of shedding following rainy days as compared with rates for young bolls whose flowers had opened during rainless weather.

Varietal differences in shedding responses to cloudy conditions. It may be seen in fig. 6-A that the Rogers Acala variety of cotton began to shed its young bolls somewhat earlier than the Stoneville 2B plants of the same age, apparently in response to the cloudy-weather stimulus occurring a few days previously. The higher shedding rate of the Acala variety was first apparent on April 16 and this difference was noticeable until April 23. Stoneville 2B did not show this first marked response in shedding until about 2 or 3 days later, and the shedding peak also occurred 2 days later (April 28 instead of April 26). In view of the fact that an early set of bolls is characteristic of the Stoneville 2B variety, this early shedding might indicate a considerably greater sensitivity to the shedding stimulus in the Acala variety. Later, during May, the shedding graphs are quite similar for the two varieties. On the average, both varieties, up to the time of harvest, had shed 16 young bolls per plant although the average Stoneville 2B plant in this test had 13.6 bolls and showed a final set of 46 percent as compared with 10.1 bolls and 39 percent set for the Rogers Acala.

In a greenhouse test of six varieties during the early spring of 1944, three of the varieties (A. D. Mebane Estate, Qualla, and Rogers Acala) showed (fig. 6-B) a marked early shedding of young bolls, beginning on April 18 and reaching the highest peak on April 22. This early shedding was preceded by three days of cloudy weather from April 17 to 19. The other three varieties (Stoneville 2B, Deltapine 14, and Half and Half) showed practically no shedding during this period, although all varieties commenced blooming at practically the same time. These results are comparable with data reported later showing a higher degree of sensitivity in certain varieties to unfavorable light conditions.

Seasonal Differences in Fruiting and Shedding

During the summer of 1941, the check plants in an experiment with the Rogers Acala variety produced an average of 24 bolls per plant. Under greenhouse conditions in the late fall, plants of this same variety, grown in the same kind of sand and with a nutrient solution of similar composition, produced only 6 bolls per plant. It was also noted that the fall-grown plants were nearly equal in fresh weight of leaves and stems and also in height to those grown during the summer. These results led to the comparison in 1943 of three series of plants; spring, summer, and fall, each containing 140 plants; these were comprised of 14 plants each of 10 varieties, 8 of which were grown in sand culture and 6 in soil. The results of this test, with the data for all varieties averaged together but with the sand and soil plants listed separately, are shown in table 2.

In this table, attention might be called first to the close similarity between the sand-grown plants and those grown in soil, in regard to size and fruiting capacities. Also, the vegetative growth and fruiting behavior of the cotton plants in the greenhouse during the spring are much more closely comparable with those raised outdoors in the summer than with the greenhouse fall plants; the greatest difference between the spring and summer series was a somewhat smaller boll weight for the former.

In comparing the fall series of plants with the summer series, a tendency towards a marked reduction in fruiting capacity was found in the fall plants and a less striking difference in vegetative growth. The fall plants in the greenhouse, as may be seen in the fall : summer ratio in the last column of table 2, were nearly equal in height to the summer plants, although the difference in height shown between the two seasons was found significant. The fall plants were one-third smaller in regard to fresh weight of leaves and stem, and the differences were again found to be significant. Likewise, a highly significant difference was found between summer and fall plants in regard to number of blooms per plant. At the same time, the fruiting of the fall plants was greatly reduced—amounting to only 35 percent of the summer plants in number of bolls produced, and to only 29 percent in the fresh weight of bolls (both differences are significant at the 1 percent level). The percent-set and fruiting-index figures are likewise low for the fall plants and are equal to only one-half or less of the comparable figures for the summer series. An explanation of at least a large part of these differences seems to lie in the relatively larger number of bolls shed in the fall series. There was no significant difference between summer and fall in regard to total number of bolls shed per plant. This large number of bolls shed in the fall, together with a decrease in number of blooms, accounts for the much lower percent-set in the fall-winter series. Even though a smaller yield might be expected in the fall, a correspondingly low percent-set figure might also be expected provided the plants had similar fruiting tendencies during both seasons. The fruiting index was less than half as large in the fall as in the summer. These results indicate that some factor (or factors) aside from vegetative growth and aside from square formation is contributing to a marked degree towards the impaired yield of bolls in the fall-grown

Table 2. Vegetative growth and fruiting behavior of cotton plants in sand and soil culture at different seasons of the year. Average of 10 varieties—80 plants in sand, 60 in soil, in each of the three seasonal series, 1943.

Data per average plant	Spring (greenhouse)		Summer (outdoors)		Fall (greenhouse)		Ratio Fall : Summer (sand & soil)
	Sand	Soil	Sand	Soil	Sand	Soil	Percent
Height—cm.	96	86	92	90	86	87	95
Weight[1] stem and leaves—g.	281	296	288	263	189	183	68
Number of blooms	32	31	30	33	23	22	71
Number of bolls shed	17	16	14	15	17	16	114
Number of bolls set	15	15	16	18	6	6	35
Per cent of bolls set	47	48	53	55	26	27	49
Weight[1] of bolls—g.	357	304	435	487	126	138	29
Fruiting index[2]	1.3	1.0	1.5	1.9	0.7	0.8	44

[1]Fresh weight.

[2]Weight of bolls divided by weight of stem and leaves.

Fig. 7. Two cotton plants (leaves removed in lower picture) showing relatively poorer set of bolls by Lone Star variety on left as compared with Deltapine 14 variety on right, when grown under winter greenhouse conditions. In this experiment, the former variety averaged 3.2 bolls per plant while the latter averaged 9.4 bolls (6 plants in each case). In the upper photograph, it may be seen that the two varieties made a similar amount of vegetative growth.

plants. Heavy shedding of young bolls appears to be a factor worthy of consideration in this connection.

The following facts concerning the weather conditions during the period of growth of the plants following opening of the first blooms, in each of the three series at different seasons, may be significant. During the 45 days preceding harvest of the summer series there were 11 cloudy days as compared with 19 cloudy days during this same relative period in the fall series. There were therefore, over 70 percent more cloudy days during the blossoming period in case of the fall plants as compared with those in the summer series. There were only 7 cloudy days in the same relative period for the spring series of plants.

The length of day for these same periods was on the average: 13 hours for the spring series, 14 hours for the summer, and 10 1/3 hours for the fall series. In connection with a consideration of the effects of day length on cotton it may be recalled that Berkley (9) found this factor to be of little importance ordinarily, as far as formation of flower buds was concerned. Berkley did report, however, an important interaction between length of day and temperature, in relation to the production of squares. The following quotation from correspondence with Dr. John W. Shive (49) is of considerable interest at this point, since he grew cotton plants to maturity at different seasons of the year in a greenhouse at New Brunswick, New Jersey, where seasonal differences in length of day are much greater than those for Central Texas: "We have carried out considerable work with the cotton plant here, but I have never noticed any sensitiveness of this plant to length of day. We have grown it both in summer and in winter. It grows more slowly in the winter time than in the summer time and does not get as large in winter as in summer. It seems to bloom regularly and without much change in the cycle at any time of the year. It may be that some varieties are more sensitive than others, but I do not know anything about this. None of the work that we have done would indicate whether the plant is sensitive to length of day, but I do know that changes in temperature make a marked difference in the manner of its growth." There is no doubt but that the lack of sensitiveness on the part of cotton mentioned by Shive refers to the ability of the plant to grow and bloom well under widely different day-length conditions. Indications that length of day may be important in the accumulation of a sufficient *amount of light*, however, to provide optimum conditions for cotton fruiting are presented in the following section of this bulletin.

The importance of temperature, also noted by Shive, cannot be overlooked especially in regard to growth differences of the cotton plants at different seasons of the year. As shown in fig. 2, the average daily temperature is much higher in the summer than under greenhouse conditions in the winter or in the spring. Since the growth of the plants in the spring was found to equal or to exceed the growth in winter, it could be assumed that the improved light conditions (longer days and less cloudy weather) were more important than the temperature differences which were somewhat similar in these two seasons (fig. 2, B and C). Data to be presented herewith indicate further that a few days of shade or reduced day length may also lessen cotton fruiting processes, under approximately identical temperature conditions.

Varietal differences in response to seasonal variations. Part of the data in table 2 has been reassembled according to varieties in table 3 to show varietal differences in growth and fruiting between culture during the late fall in the greenhouse and comparable culture outdoors during summer. The ten varieties of cotton used here include: Deltapine 14, Roldo Rowden, Stoneville 2B,. Coker 4-in-1, Half and Half, Washington, A. D. Mebane Estate, Qualla, Rogers Acala, and Lone Star. The data recorded in table 3 represent the average of 14 plants—8 in sand and 6 in soil—for each variety. The measurements in the summer are given just above those for the fall in each case and the ratio, given just below these two figures, shows the relative value of the fall data as a percentage of the summer value. Therefore, the varieties with the largest percent figures for a ratio represent the ones least seriously affected by the fall conditions. The varieties have been arranged in this table so that those (Stoneville 2B, Half and Half, Washington, Roldo Rowden, Coker 4-in-1, and Deltapine 14) showing the smallest effect on fruiting capacities from the adverse environmental conditions in the fall appear on the left side. The varieties more seriously affected (Rogers Acala, Lone Star, Qualla, and Mebane) in respect to fruiting processes, as indicated by number of bolls set, weight of bolls, percent-set and fruiting index, are listed on the right side of table 3. It may also be seen that the difference between varieties, in regard to their responses to unfavorable fall conditions, is much less in the case of the vegetative processes, such as height and weight of plants, and in the number of flowers produced or number of bolls shed, than in case of the above fruiting process (see fig. 7).

Statistical analysis of the data, which have been summarized in table 3, pertaining to the number of bolls set, number of bolls shed, and the fresh weight of the plant showed significant interactions (1 percent level) between varieties and seasons. The interaction between varieties and seasons for boll weight was significant at the 5 percent level. There were no significant interactions in the data on plant height. These facts would indicate that certain varieties reacted differently than others, in regard to some characteristics, to the fall conditions as compared with summer performance. Further confirmation of varietal differences in response to seasonal effects is shown in the ratio figures computed for each variety and for each type of data. The difference required for significance between varieties in these ratios is shown in the last column of the table. Examination of the ratios shows that the four varieties on the right (Lone Star, Mebane, Qualla, and Rogers Acala) were adversely affected in their fruiting activities in the fall to a greater extent than the other varieties tested. In regard to impairment of growth processes in the fall, however, the difference between varieties is small and in most cases insignificant.

The differences between the ten varieties in regard to growth and fruiting tendencies in summer and fall are shown graphically in fig. 8.

Effects of Reducing the Number of Hours of Sunshine per Day

In order to obtain some information as to the factors causing the differences in fruiting capacity of cotton at different seasons of the year, certain experiments were conducted in which the number of hours per day of sunshine on the plants was made a variable factor. In this manner, it was hoped to learn whether the decrease in fruiting capacity already noted in the fall-and-winter series, as compared with spring and summer series, might be due mainly to lower light intensities during the fall and winter or to some other factors.

Table 3. Vegetative growth and fruiting of ten cotton varieties in the summer (outdoors) and in the late fall (greenhouse). Average of 14 plants of each variety. 1943

Type of data	Season	St.2B	H&H	Coker 4-1	Wash.	Roldo Rowd.	DPL 14	Rog. Acala	Meb. Est.	Qual-ia	Lone Star	Diff. req.[1]
Height cm.	Summer	90	90	92	88	91	93	96	89	92	90	
	Fall	81	89	88	81	89	90	90	82	90	87	
	Ratio F/S, %	90	99	96	92	98	97	94	92	98	97	8.3
Weight of stem and leaves—g.	Summer	263	241	258	276	278	253	288	310	284	320	
	Fall	182	176	180	189	197	155	206	180	182	214	
	Ratio F/S, %	69	73	70	68	71	61	72	58	64	67	18.1
Number of blooms	Summer	34	36	39	31	28	39	34	27	27	24	
	Fall	23	30	28	23	23	27	25	18	19	17	
	Ratio F/S, %	68	83	72	74	82	69	74	67	70	71	19.0
Number of bolls set	Summer	19	20	23	16	16	24	17	12	12	11	
	Fall	8	9	11	7	6	8	6	4	4	4	
	Ratio F/S, %	42	45	48	44	38	33	35	33	33	36	7.0
Number of bolls shed	Summer	15	16	16	15	12	15	17	15	15	13	
	Fall	15	21	17	16	17	19	19	14	15	13	
	Ratio F/S, %	100	131	106	107	142	127	112	93	100	100	36.4
Percent set	Summer	56	56	59	52	57	62	50	44	44	46	
	Fall	35	30	39	30	26	30	24	22	21	34	
	Ratio F/S, %	63	54	66	58	46	48	48	50	48	52	10.2
Weight of bolls	Summer	505	427	522	455	518	495	446	408	420	426	
	Fall	172	157	184	141	140	138	107	85	100	104	
	Ratio F/S, %	34	37	35	31	27	28	24	21	24	24	9.5
Fruiting Index	Summer	1.9	1.8	2.0	1.6	1.9	2.0	1.6	1.3	1.5	1.3	
	Fall	1.0	.9	1.0	.7	.7	.9	.5	.5	.6	.5	
	Ratio F/S, %	53	50	50	44	37	45	31	38	40	38	5.6

[1]Difference necessary for significance at the 5 percent level.

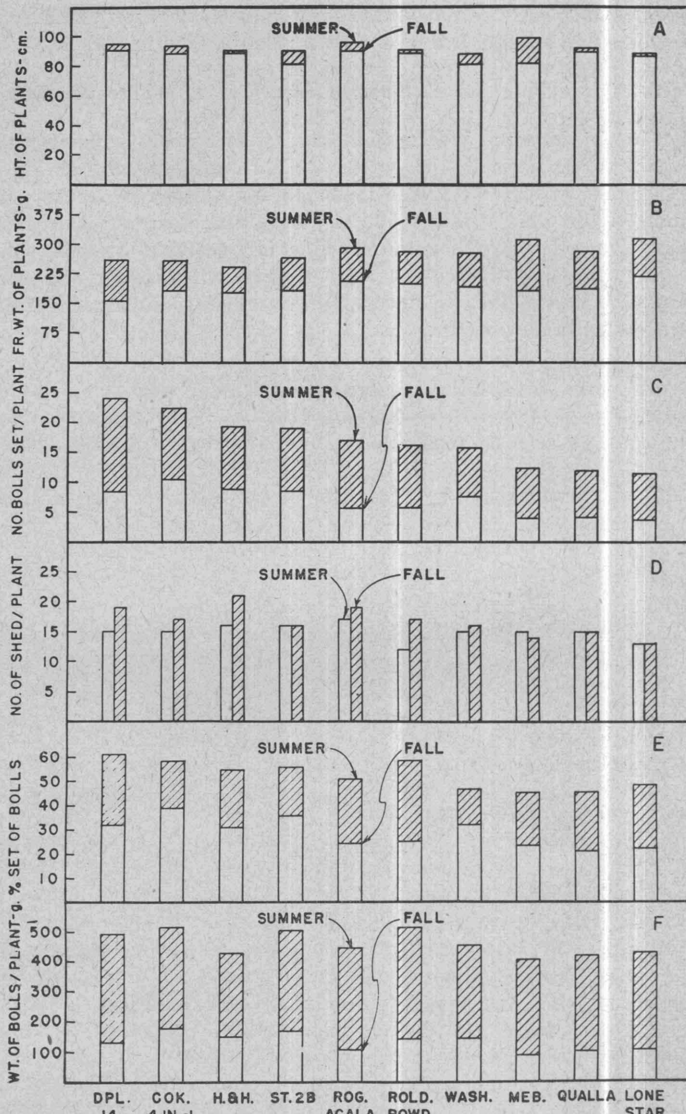


Fig. 8. Graphical representation of differences (shaded blocks, except in D) in growth and fruiting of ten varieties of cotton in the summer (outdoors) and in the fall (greenhouse). A. Height of plants; B. Fresh weight of stem and leaves; C. Number of bolls set per plant; D. Number of bolls shed per plant; E. Percentage of bolls set; and F. Fresh weight of bolls per plant. There were 14 plants (8 in sand and 6 in soil) of each variety per season. Note the relatively large differences between the summer and fall values in the case of bolls set (C), percent set (E), and weight of bolls (F), while smaller differences exist in the height, (A) and weight of plants (B), and number of bolls shed (D).

In these experiments, the plants were shaded with light-impervious airplane fabric. This was supported over the plants in the greenhouse by a pole hung over the center of the bench and the cloth was draped over the outside of the jars on both sides (fig. 9). Outdoors an inverted U-shaped structure was constructed over a row of plants, high enough to allow one to walk alongside of the plants beneath the shade cloth. The ends of the shades were left open in every case to allow free circulation of air and to prevent temperature increases under the shade. A light intensity of less than 50 f.c. was recorded on guard plants placed a few feet inside the ends of the cloth. In the center of these shades, with the light-meter target registering light from any direction the intensity was less than 10 f.c., with bright sunshine on the outside.

In the greenhouse experiment in the spring of 1944 six varieties of cotton were used: Stoneville 2B, Rogers Acala, A. D. Mebane Estate, Deltapine 14, Qualla, and Half and Half. In this case the treated plants were covered each afternoon at 3:00 o'clock (C.S.T.) and the shade was allowed to remain over the plants until 8:00 o'clock the following morning. This same treatment was repeated in a series of four varieties of

Fig. 9. Airplane fabric shade placed over cotton plants during late afternoon and early forenoon to study effect of variation in number of hours of sunshine per day. Close-spaced plants are on the right.

cotton (two plants each of: Stoneville 2B, Rogers Acala, A. D. Mebane Estate, and Half and Half per treatment) during the summer. At the same time, another treatment with a comparable set of summer plants consisted of shading of the plants from 10:00 o'clock in the morning until 1:00 o'clock in the afternoon. All of the plants in these experiments were grown in 4-gal. jars of soil.

It was desired to ascertain by these experiments whether decreased fruiting of cotton in the fall might be due to the lower light intensity or to the short-day effect at that time of the year. Consequently, these experiments might be classified as dealing with length of day but since no attempt was made to exclude light totally by the manner in which the shading was applied, it seems preferable to consider the treatment merely as a decrease in the number of hours of direct sunlight per day. This work is distinctly different from so-called photoperiodism experiments in which the length of day is usually studied in relation to flower bud formation or to the period of blooming. As mentioned earlier, the cotton plant is not particularly sensitive to variations in length of day in regard to growth and to formation of flower buds.

The results of these two experiments on variations in the number of hours of sunlight are given in table 4. In the greenhouse test, there was no significant difference between the check and shaded plants in regard to height and weight. The reduction in number and weight of bolls due to the treatment was highly significant. In the two outdoor experiments, there was a significant increase in height and weight of plants, while the number of bolls set and weight of bolls showed a significant decrease in each case. The reduction in number of hours of sunshine in every case resulted in decreases in the data associated with fruiting capacity. In this respect the results resemble those presented later for shaded and close-spaced plants. It may be noted that the shade applied for three hours near the middle of the day was apparently more inhibitive to the fruiting processes and induced more shedding than the shade treatment from 3 P. M. to 8 A. M., although these differences were not significant in most cases.

Analysis of variance showed no significant interaction between varieties and the short-day treatments. However, on a percentage basis (ratio between short-day treated plants and the checks), the fruiting activities of the Lone Star, Qualla, Mebane, and Rogers Acala varieties were reduced to a greater extent than those of the Half and Half, Stoneville 2B, and Deltapine 14 varieties. This same trend in ratios for fruiting processes was found following each of the three experiments in table 4. In vegetative growth, these ratio differences were less marked, and the differences between the two above groups of varieties were not consistent. The shedding curves in fig. 10 also indicate a greater sensitivity to short-day effects on the part of the Qualla and A. D. Mebane Estate varieties than in the other four varieties under comparison.

Table 4. Effect of reducing the total number of hours of sunshine per day on cotton plants. Data per average plant.

Treatment	Number of plants	Height cm.	Weight of plant g.	Number of blooms	Number bolls set	Number bolls shed	Weight of bolls g.	Percent set	Fruiting index
Planted February 3, 1944—Shade, March 30 to May 10—6 varieties—greenhouse									
No shade	36	97	294	32	14	18	293	44	1.0
Shade—3 P. M. to 8 A. M.	36	94	253	21	8	13	162	38	.6
Planted April 6, 1944—Shade, June 26 to July 25—4 varieties—outdoors									
No shade	8	79	231	37	16	21	361	43	1.6
Shade—3 P. M. to 8 A. M.	8	88	285	29	11	18	240	38	.8
Shade—10 A. M. to 1 P. M.	8	99	278	32	9	23	185	28	.7

The effects obtained from these shade treatments suggest that high light intensity is not as important as the length of the period of adequate illumination insofar as fruiting processes in cotton are concerned. In other words, the same detrimental effects on fruiting in cotton as seen in the low-light-intensity days of fall and winter can be duplicated during seasons of high light intensity by merely shortening the daily period of illumination. This conclusion appears justifiable since the treated plants, in the summer series at least, were exposed to high light intensities for 7 hours in one case (early morning and afternoon shade) and for about 10 hours in case of the noonday shade. Furthermore, these periods of high intensity correspond rather closely with the 7 to 10 hours of sunshine available to the plants during the fall-winter series. As shown in table 1, the light intensity on the plants in the summer was considerably higher than that during the fall and winter months. The temperature factor again seems to be much less important than the light effects, since here both the spring and summer treatments, which produced effects similar to those obtained in the fall, were applied under temperature conditions even more favorable for cotton fruiting than those prevalent in the greenhouse during the shorter fall-winter days.

Effects of Supplemental Lighting on Cloudy Days

During the late fall and winter, 1941-1942, thirty-two Rogers Acala plants (planted September 4) were grown in soil on a north greenhouse bench along the center of which 300-watt Mazda Reflector Flood electric lamps in 18-inch porcelain reflectors were suspended at 8-foot intervals (fig. 11). The plants were arranged along each side of the bench in two rows so that four plants received illumination from each lamp and a group of four plants between these received practically no light from the lamps.

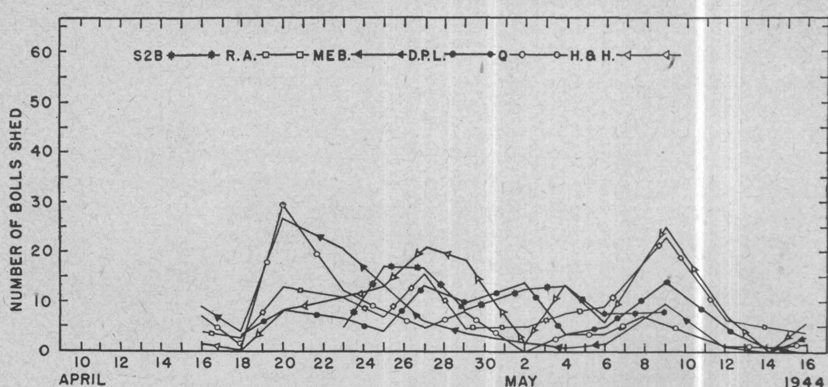


Fig. 10. Shedding curves for six varieties of cotton under short-day conditions (heavy shade from 3 P. M. to 8 A. M.). Note relatively heavy shedding by the Qualla and A. D. Mebane Estate varieties early in the fruiting period. Compare this figure with fig. 6-B (check plants for this same series) and note relatively greater amount of shedding by all varieties under short-day conditions, in the first half of this period.

The lights were used on all or parts of 23 different days, whenever the sky became completely overcast, beginning about the middle of November. On a clear afternoon (2:30 P. M.) in December the average of several light-intensity readings over this bench was 5200 f.c. At the same hour on a cloudy day, this average was about 250 f.c. between the lamps, while readings taken seventeen inches below the lighted lamps showed about 1000 f.c. intensity.

The plants were harvested on January 22 and considerable difference was found between the groups (illuminated and nonilluminated) in vegetative growth. In fruiting behavior, however, there was but little difference between the two groups. The plants that received the extra light on cloudy days were taller and averaged 102 cm. in height as compared with 84 cm. for the nonilluminated plants. This difference in height was due

Fig. 11. Effects of supplemental light on cloudy days on growth of cotton plants under winter conditions in the greenhouse. The plants directly beneath the lamps made much more growth in height.

to increases in length of internodal spaces, however, since both groups of plants had 20 nodes to the stem on the average. The average illuminated plant had 53 expanded leaves while the check plants had 49 leaves. The average number of bolls per plant was practically the same for the illuminated plants (7.7 bolls) as for the check plants (6.9 bolls). In both groups, 40 percent of the flowers formed mature bolls. A significant difference between these two groups of plants was found in the fresh weight of bolls at harvest; each illuminated plant had a fresh boll weight of 220 g. per plant. whereas the weight for the average nonilluminated plant was 187 g. This increase in weight of bolls has also been found associated with the better light conditions in other experiments reported herein. It seems, however, that the additional light provided by the electric lamp was not sufficient in this case to increase materially the number of bolls set or to change the rate of shedding, but the height of the plants and the weight of bolls were markedly increased by the supplemental illumination on cloudy days.

EXPERIMENTS WITH LOW LIGHT INTENSITIES

Most of the studies reported here on the effects of artificially-produced low light intensities on shedding and fruiting in the cotton plant have involved brief periods of treatment lasting usually from two to eight days. Such treatment-periods have been used in an effort to reproduce approximately the time intervals involved in ordinary periods of cloudy weather. The materials used for shading have, in most cases, reduced the light intensity from around 10,000 to 12,000 f.c. at midday to 50 to 3000 f.c. on the shaded plants at the same time. These low light intensities are within the ranges of intensity measurements made during overcast weather as shown in table 1. Other experiments have involved the growing of cotton plants for a period of several weeks, during the fruiting period, under constant low-light-intensity conditions (1000 to 4000 f.c. noonday sunlight), that might simulate continuously cloudy weather.

Continuous Low Light Intensity During the Fruiting Period

Four separate tests were made of the effects of continuous periods of shade on the fruiting process in cotton. The first of these tests was conducted during the summer of 1941 with sixteen Rogers Acala plants which were kept in a section of the greenhouse that was covered with slat shades from the time the first blooms appeared until the oldest bolls started to open. On the average, these plants each produced 5 bolls and each shed 8 immature bolls, making a boll-set of 38 percent. The plants were exceedingly tall with long internodes. Check plants outdoors produced 24 bolls with 19 bolls shed, or 56 percent-set. This experiment was repeated in the summer of 1944 using 18 plants (3 each of 6 varieties: Stoneville 2B, Rogers Acala, A. D. Mebane Estate, Deltapine 14, Qualla, and Half and Half) in 4-gal. jars of soil, with the results shown in the first part of table 5. The shaded plants were significantly taller and heavier than the outdoor checks, while there was a significant reduction in number of bolls set and in weight of bolls as a result of the shade. Photographs of one of these plants may be seen in fig. 18.

In order to avoid any possible heat effects from greenhouse temperatures during the summer, a third test was set up outdoors with 14 plants (8 of Stoneville 2B and 6 of Rogers Acala variety), also in 4-gal. jars of soil, during the late summer, 1944. In this case the plants were shaded by placing them at time of first blooming, under a slatted greenhouse roof shade supplemented with black cloth (fig. 12). The light intensity under this shade varied from 1000 to 2000 f.c. at noon on clear days, depending upon the direction in which the light-meter target was held. Temperature records showed no increase over those taken in the shade among the control plants. The results given in the second part of table 5 were similar to those obtained earlier in the shaded greenhouse. The shaded plants were significantly taller although not quite as heavy as the checks. There was a significant reduction in the number of bolls set and in weight of bolls and the percent-set was much less for the shaded plants.

Another experiment, conducted in the greenhouse in the spring of 1944, involved the use of white cloth shade over 16 plants (8 of Stoneville 2B and 8 of Rogers Acala) in sand culture. The plants were shaded continuously beginning with the opening of the first blooms. On clear days at noon, the light intensity on the upper leaves of the plants under this white cloth shade was about 2000 f.c. The results of this experiment are given in the last section of table 5.

These experiments with cotton plants under conditions of continuously low light intensity indicate that the fruiting processes are considerably inhibited by the reduced amount of light. These results might be interpreted as indicative of the fruiting behavior of cotton during an extended period of continuously cloudy weather. Even with the low light intensities under the shade in these experiments, it should be noted that the height and fresh weight data for the continuously shaded plants were

Fig. 12. Greenhouse slat shades, supplemented with black cloth for shading plants outdoors in the summer. The temperature readings beneath this shade did not exceed those taken at the same time among the lower leaves of nearby plants exposed to the sun.

Table 5. Effects of continuous shade throughout the fruiting period on growth and fruiting of cotton. Average per plant

	Approx. noon intensity f. c.	Height cm.	Weight of plant g.	Number of blooms	Number of bolls set	Number of bolls shed	Weight of bolls g.	Percent set
Under greenhouse shades, 18 plants per treatment, early summer 1944								
Check	14,000	81	228	35	15	20	344	43
Shade	2,000	128	320	36	9	27	128	25
Outdoor shade, 7 plants per treatment, late summer 1944								
Check	13,000	86	263	35	17	18	374	49
Shade	1,500	112	228	21	3	18	31	14
White cloth shade, greenhouse, 16 plants per treatment, spring 1944								
Check	10,500	81	208	24	12	12	248	50
Shade	2,000	101	224	19	8	11	163	42

greater than those for the controls, with the single exception of the fresh weight of the outdoor series (heaviest shade). In one series (early summer, 1944) it may be noted that the number of open flowers was the same for the shaded plants as for the check plants. There was a difference of 5 blooms per plant in the greenhouse series when white cloth shade was used. The greatest difference in number of blooms (14 per plant) occured in the outdoor series where the heaviest shade of all of the treatments was used.

The difference in shedding between the shaded plants and the controls is quite marked as shown by the percent-set figures. The greatest difference (49 vs. 14 percent) occurred with the heaviest shade (1500 f.c.) in the outdoor series. The reduction in fresh weight of bolls per plant following the shade treatments was severe in each case. The greatest diffrence (343 g. per plant) was associated with the smallest number of bolls and occurred under the heaviest shade. Increased shedding in all three series was associated with the experimental shading and the excessive shedding that was induced could account for the small number of bolls and, at least in part, for the inferior weight of bolls on the shaded plants.

Periods of Low Light Intensities

Evidence of severe shedding following a period of low light intensity was obtained early in this work when two cotton plants, demonstrating the effects of high and low nitrogen applications in sand culture, were exhibited for two days in a hotel lobby at Waco, during the Second Cotton Research Congress, June, 1941. When the plants were returned to their former places outdoors at College Station, all young bolls, flowers, and squares of all sizes had been shed. In order to ascertain experimentally the effects of such periods of a few days of low light intensity, which also might accompany spells of cloudy or rainy weather, cotton plants were shaded at definite intervals and the differences in subsequent growth, shedding, and fruiting were noted. The first planned experiment of this sort (16) was conducted in the summer of 1941 when eight Rogers Acala plants (started April 23) were shaded outdoors with black cloth for four days (July 8-12) after several blossoms had opened on each plant. On August 3, these plants had on the average 12 bolls per plant and they had shed 24 fruiting forms. The nonshaded control plants at the same time had, on the average, 23 bolls and only 18 scars where forms had been abscised. The percent-set for the shaded plants was only 33 while the corresponding figure for the check plants was 56. The shedding curves for these two sets of plants are shown in fig. 13. Here it may be seen that a peak in shedding for the shaded plants occurred on July 12—the day the shades were removed. This was followed by high points in the shedding curve for the shaded plants on July 15 and 17. The control plants also showed an increase in the shedding rate on July 15 and 17 apparently in response to cloudy weather starting on July 10 and lasting until July 19. This peak in the check-plant curve, however, is not as high as the curve for the shaded plants at this point, although the latter plants had already shed many more forms than the checks. The next high shedding rate for the check plants started on July 25 and lasted until the time of harvest on August 3. These final peaks may have been associated with several days of cloudy weather from July 13 to 19 followed by another cloudy period starting on July 24. The exceptionally high peak of shedding on July 25 for the plants that were shaded earlier is of considerable interest since it shows increased shedding activity in plants that had already shed heavily. Moreover, this second shedding peak occurred somewhat earlier than the corresponding peak for the control plants. This indicates that conditions which cause a cotton plant to show an abnormally high shedding rate immediately might also predispose the plant to more serious shedding later and make it more sensitive to subsequent shedding-inducing stimuli.

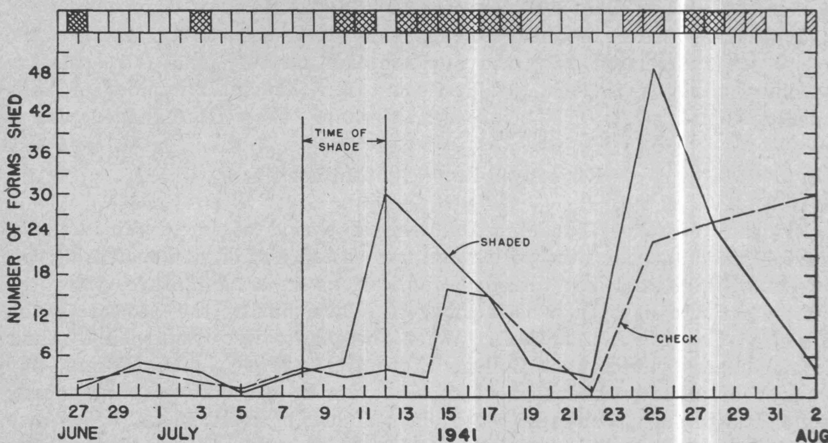


Fig. 13. Shedding curves showing effects of 4-days shade, applied July 8-12, to 8 Rogers Acala plants. Note immediate effect of shading shown by increase in shedding on July 12 as compared with the curve for 8 nonshaded plants (check). Another sharp peak of shedding for the shaded plants on July 25, apparently caused by the cloudy weather July 10-19, is also of interest.

This experiment was followed by one in the greenhouse in the spring of 1942 in which three sets of 8 Stoneville 2B cotton plants each, planted January 9, were used. One set served as checks while the second was shaded with white cloth on Monday, Wednesday, and Friday of each week from March 23 to May 5 and the third set was shaded with black cloth on these same days. The plants were harvested on May 8 and the following numbers of bolls per average plant were obtained: checks, 21; white cloth shade, 18; black cloth shade, 15. The average weights of bolls per plant were 411, 312, and 249 g., respectively. There was but little difference in the percent-set figures for the three groups.

Following these preliminary tests, several experiments on shading of cotton were conducted under both greenhouse and outdoor conditions. The results of five experiments, including the most significant of these studies are given in table 6. With the exception of the test in the spring of 1944, in which 4-gal. jars of soil were used, the plants were all grown by the sand culture method. Two of the experiments were in the greenhouse (spring series) and the three summer tests were made outdoors. Black cloth was used for shading in all cases although in the late summer 1944 experiment its use was supplemented by the slat shades, fig. 12. In the second summer series (planted June 25, 1942) in table 6, half of the plants were subjected to a second period of shade by placing them in a laboratory room for six days, following an earlier period under black cloth. The first column of figures in this table shows the light intensities on the shaded and nonshaded plants near noon on a clear day.

In the first experiment (1943) shown in table 6, 16 plants each of Stoneville 2B and Rogers Acala varieties were used—4 plants of each variety per treatment. The first shade treatment consisted of black cloth shade placed over the plants on Monday, Wednesday, and Friday of each of the first three weeks in April; the second treatment involved two 4-day periods of shade beginning on April 3 and 24, respectively; and the third treatment was one of 6 consecutive days of shade beginning April 13. Statistical analysis of the results of this greenhouse test shows that the differences in height were not significant although each of the treatments showed a taller average plant than the checks. This same condition was found in the data on fresh weight of plants. As compared with the checks, all three shade treatments produced smaller numbers of bolls per plant (significant at the 1 percent level). There was no significant difference between the shade treatments, however, in regard to number of bolls. The number of forms shed in all three shade treatments was significantly different (at the 1 percent level) from the checks, and a significant difference between the 3-days per week and other treatments was also found in this case. Again, all three shade treatments produced a significantly (1 percent level) smaller weight of bolls than the checks, but here the differences between the shade treatments were not significant. The percent-set figures show a sharp reduction in case of the treated plants.

The second part of table 6 is comprised of data taken under greenhouse conditions from 6 plants of each of 6 varieties in the case of the checks and from 5 plants of the same varieties (Stoneville 2B, Rogers Acala, A. D. Mebane Estate, Deltapine 14, Qualla, and Half and Half) in case of the 4-day shade treatment. The increases in height and fresh weight of the shaded plants were highly significant in this experiment as were the decreases in number and weight of bolls. Inasmuch as the period of treatment was relatively brief, it may be assumed that these vegetative differences were due to increased growth following the loss of fruiting structures by shedding rather than to an etiolation effect during the period of low light intensity. The data on shedding, 22 forms from the checks and 26 from the treated plants, are not comparable since nearly all the shedding recorded for the shaded plants occurred during or just after the treatment and many squares of various sizes were involved. The shedding curve (not shown) for this experiment had a sharp peak for all varieties on April

Table 6. Effects of few-day periods of shade on growth and fruiting of cotton

Treatment	Approx. noon light intensity, f. c.	Number plants per treatment	Average data per plant					
			Height cm.	Weight stem and leaves g.	Number of bolls set	Number of forms shed	Weight of bolls g.	Percent set
Spring Series—In Greenhouse								
Planted January 9, 1943—Harvested May 7								
None	9,800	8	97	308	18	13	384	58
Shade—Mon., Wed., Fri., 4/5–23	350	8	105	324	9	20	179	31
Shade 2 periods (4 da.) 4/3–7 & 4/24–28	350	8	116	365	7	25	156	22
Shade 1 period (6 da.) 4/13–19	350	8	113	323	7	27	142	21
Planted February 3, 1944—Harvested May 18								
None	10,800	36	97	294	14	22	293	39
Shade—4 days, 4/10–14	300	30	115	413	4	26	80	13
Summer Series—Outdoors								
Planted May 12, 1942—Harvested August 24								
None	13,400	6	96	248	16	26	305	38
Shade, 7/21–25 and 7/31–8/3	450	6	118	307	7	25	193	22
Planted June 25, 1942—Harvested October 19								
None	14,000	8	80	235	18	13	386	58
Shade, 9/11–13, in lab. room, 9/18–24	500–50	8	95	290	6	20	135	23
Planted June 24, 1944—Harvested September 15								
None	14,500	7	86	263	17	18	383	49
Shade—2 da., 8/22–24	1,500	7	88	305	17	21	391	45
Shade—4 da., 8/22–26	1,500	7	89	320	12	17	316	41
Shade—6 da., 8/22–28	1,500	7	99	349	10	23	223	30
Shade 2 periods of 3 da., 8/22–25 & 9/8–11	1,500	7	94	340	8	32	194	20
Shade (late) 4 da., 8/28–9/1	1,500	7	87	317	14	22	317	39
Shade (late) 4 da., 9/4–8	1,500	7	87	329	18	24	330	43
Difference required for significance at 5% level	....	....	....	54	6	6	133	....

17 following removal of the shade on April 14. About one-half as many shed forms were recorded on April 15 as on the 17th and many of these had dropped before removal of the shade. Following this peak the shedding fell off abruptly to a low rate on April 19 and 23, after which there was practically no further shedding up to the time of harvest of the plants (May 15). The shedding graph for the check plants in this same experiment is shown in fig. 6-B, in which peaks occur about April 26-28 and May 3. In this experiment, again, the 13 percent-set for the shaded plants is relatively low and amounts to only one-third of the corresponding figure for the check plants.

The first of the three outdoor summer series shown in table 6 was made up of 12 Rogers Acala plants. The treatment in this case consisted of black cloth shade for 4 days beginning on April 10. The differences obtained between the checks and shaded plants in regard to height and number of forms shed are not significant. However, the increase in weight of plants and decrease in weight of bolls were found to be significant at the 5 percent level. The reduction in number of bolls is highly significant. There was practically no increase in the number of forms shed but the smaller percent-set in the case of the shaded plants is in keeping with the other experiments in this table.

The results of the second outdoor shading experiment, conducted with a late summer series of plants in 1942, are shown in the fourth section of table 6. In this case 8 plants of the Stoneville 2B variety were used as checks and 8 comparable plants were shaded outdoors for 2 days and later placed in a laboratory room for 6 days. The difference shown in height measurements is significant at the 5 percent level while the differences in weight of plants, number of bolls set, number of forms shed, and weight of bolls are all significant at the 1 percent level. The usual reduction in percent of bolls set is evident in this test.

The last experiment listed in table 6 was conducted outdoors in the late summer of 1944 with 4 plants of Stoneville 2B and 3 of Rogers Acala variety per treatment. The treatments in this case consisted of placing the plants under the slat and black-cloth shade shown in fig. 12. The first three treatments in this experiment, as listed in the last section of table 6, consisted of 2, 4, and 6 days of shade, respectively, beginning on August 22. The fourth shade treatment consisted of two periods of 3 days each, beginning on August 22 and September 8, respectively. The last two treatments consisted of 4 days under shade, the earlier treatment beginning on August 28 and the later on September 4. The differences in height of plants resulting from the shade treatments were not significant when analyzed. In the case of weight of plants, number of bolls set, number of forms shed, and weight of bolls, however, a significant difference at the 1 percent level was found between the treatments and the checks. The differences required for significance (5 percent level) in each of these cases are given below the respective figures. It will be seen that the treatments consisting of 6 days under shade and of two shade periods of 3 days each produced values significantly different from the checks in each of the four measurements and counts just noted above. These two treatments also produced the greatest reductions in percentage of bolls set, in this last experiment.

The percent-set figures for the shaded plants, in all experiments in this table, are lower than the percentages shown for the corresponding control plants. The greatest reduction (66 2/3%) in percentage of bolls set occurred in the spring series in 1944. This is in keeping with many observations in this work that indicate a greater sensitivity to shade in the fall or spring series than in the summer series. The fall and spring plants have also shown a greater tendency towards vegetative growth (see fig. 23-D), probably on account of lower reserves of carbohydrate food materials. As pointed out by Shirley (48), many kinds of plants attain maxi-

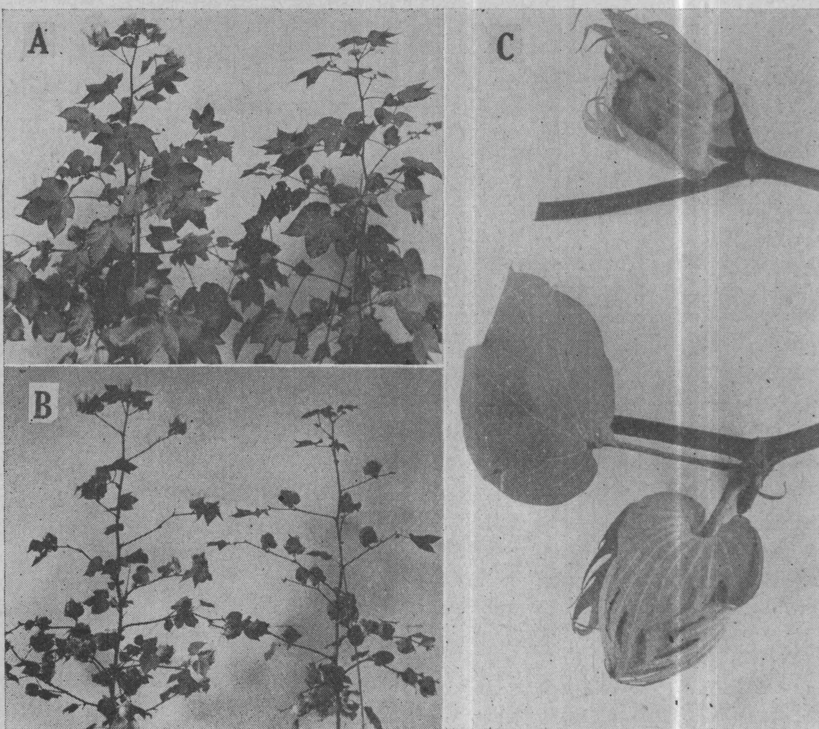


Fig. 14. Increased vegetative growth and the forcing of adventitious flower buds as a result of shading. A. and B. Photographs of two Stoneville 2B cotton plants, planted April 3, 1943; the plant on the left was shaded for 4 days (June 3-7). In B, all foliage except the youngest leaves have been removed. Note the larger number of new leaves, blooms, and nodes, where shedding has taken place, on the shaded plant, which is also larger than the unshaded check (on right). C. Adventitious bolls formed in the axils of leaves on the fruiting arms of the shaded plant. The old scars may be seen where the original bolls were shed. Photographs taken July 16.

mum vegetative growth at about 25 to 50 percent of normal summer sunlight in temperate regions, while maximum fruitfulness and dry weight occur at higher light intensities. The increase in vegetative growth and other effects of shading may be seen in fig. 14.

It may be noted in the last section of table 6 that the shortest shade treatments (2 days) produced a slight increase in number and weight of bolls. Although these brief periods of shade were sufficient to cause a peak in the shedding rate, like the one shown for 3 days of shade in fig. 22-B, the effects were not serious enough to cause a final decrease in number or weight of bolls at time of harvest.

The data on the 1944 summer series of plants are of special interest because of the comparison of periods of shade of varying duration and at different times in the fruiting period. There is a definite gradation of effects from the check plants through the 2-day, 4-day, and 6-day periods of shade. It is noteworthy, also, that the 6 days of shade provided at two different times (3 days each, beginning August 22 and September 8) produced a more serious effect on the fruiting behavior of the plants than the single peroid of 6 days (beginning August 22). A similar effect can be seen in the second shade treatment applied to the spring plants in 1943, as shown in the first section of the table. These data add further evidence of the marked effect of a second period of low light intensity following a previous period by several days. Such an effect has been shown earlier in fig. 13. It is also of interest to compare the effects of the three 4-day-shade treatments in the last section of table 6. Here, the most apparent reduction in fruiting took place in the group of plants that was shaded earliest (August 22). When shade was applied on August 28 and on September 4 less decrease in the fruiting activity of the plants resulted. These results are in accord with those reported later where different groups of plants from the same planting were placed under shade at different times during the fruiting period.

Varietal differences in response to shading. The results of two sand-culture experiments, in which comparisons were made of the responses of different varieties of cotton to a few days of low light intensity during the fruiting period, are given in table 7. Both of these experiments were conducted in the greenhouse, where plants in the fall or spring have shown greater sensitiveness to shading than those growing outdoors in the summer time. The data in the first part of this table show the Rogers Acala variety of cotton to be more adversely affected in its fruiting activity by the treatment applied than the Stoneville 2B cotton. At the same time, the Acala variety slightly exceeded the Stoneville 2B in vegetative growth under both the control and shade-treatment conditions. In this experiment the shade treatment produced, in both varieties, a highly significant effect in the case of height and weight of plants, number of bolls set, number of forms shed, and in weight of bolls. In the case of the weight of bolls, a highly significant difference was found in the interaction of varieties and treatment. This indicates a varietal difference in the fruiting responses obtained in reaction to the shade.

Table 7. Varietal differences in response of cotton to periods of shade. Average per plant.

Variety	Treatment	Height cm.	Weight of plants g.	Number bolls set	Number bolls shed	Weight of bolls g.	Per cent set
Planted Feb. 4, 1944—shaded 3 days, 4/22–25—8 plants of each var. per treatment							
Stoneville 2B	Check	75	195	14	12	281	54
	Shade	97	271	7	7	185	50
	Ratio, S/C[1]	129	139	50	58	66	93
Rogers Acala	Check	87	220	10	11	215	48
	Shade	105	287	2	7	54	22
	Ratio, S/C	121	130	20	64	25	46
Planted Feb. 3, 1944—shaded 4 days 4/10–14—check, 6 plants; shaded, 5 plants							
Stoneville 2B	Check	97	310	19	21	410	48
	Shade	107	406	7	29	142	19
	Ratio, S/C	110	131	37	138	35	40
Half and Half	Check	94	301	19	23	358	45
	Shade	117	430	6	27	100	18
	Ratio, S/C	124	143	32	117	28	40
Deltapine 14	Check	100	273	15	24	300	38
	Shade	127	414	5	26	98	16
	Ratio, S/C	127	152	33	108	33	42
Qualla	Check	90	260	10	23	241	30
	Shade	110	336	4	24	88	14
	Ratio, S/C	122	129	40	104	37	47
Mebane Estate	Check	93	275	8	23	223	26
	Shade	111	384	2	26	42	7
	Ratio, S/C	119	140	25	113	19	27
Rogers Acala	Check	106	343	12	19	223	39
	Shade	123	508	1	22	12	4
	Ratio, S/C	116	148	8	116	5	10

[1]Average for shaded plants divided by corresponding figure for the checks and expressed as percentages.

The other experiment was conducted in the greenhouse during the spring, 1944. Here, six-varieties of cotton were compared in their response to a single 4-day period of shade and the results are shown in the last part of table 7. At that time of the year, the check plants were subjected to somewhat less favorable conditions for fruiting than during the summer, as shown in table 2. The six varieties are arranged according to the number of bolls produced by the shaded plants. It may also be noted, according to the ratios shown between the checks and shaded plants, that the varieties listed first, in general, show a better maintenance of favorable fruiting following the shading, than the varieties near the bottom of the table. At the same time, the vegetative growth of all varieties was increased to a fairly uniform extent by the shade treatment. Photographs of the check and shaded plants in this experiment may be seen in fig. 23-A and D. In addition to the significance already mentioned for these data, in connection with the second section of table 6, a significant difference was found in the interaction of varieties and shading treatment in regard to the weight of bolls produced. It is of interest to note that the varieties listed first in the last part of this table, namely, Stoneville 2B, Half and Half, and Deltapine 14, are the same varieties that have been shown to be less seriously affected by fall-winter growing conditions (table 3) and by reduced day length. It should be stated that differences between varieties in experiments shown in other sections of table 6 (besides the second section) have also been found on a percentage-ratio basis. In these cases, the Stoneville 2B variety has shown higher percentages in regard to fruiting performance after shading treatment than the Rogers Acala variety. Owing to the relatively small number of plants used of each variety, however, and the tendency for all varieties to show a relatively wide variation between individual plants following shading treatment, no significance was found among the variety-treatment interactions. The differences obtained are not shown in tabular form.

Fig. 15. The center row of Coker 4-in-1 cotton was shaded with black cloth for 4 days when the first bolls were small. The shade caused considerable shedding and a renewal of vegetative growth. The photograph was taken 5 weeks after shading, following a long period of drought. The foliage of the shaded plants was still green and much heavier than that on the nonshaded rows on either side.

Effects of shading plants in the field. On July 15, 1943, black cloth shades were placed over five 25-foot single row plots of Coker 4-in-1 cotton at the Main Station Farm. The average light intensity beneath the shade was about 600 f.c. when the outside measurement was 16,000 foot candles. The plants on this date were flowering and some of the oldest bolls were about one-fourth grown. The plants were shaded for 4 days. Two days after the removal of the shades, an average of 243 young bolls and squares were recorded from beneath each of the five shaded plots, while the average number for the check plots was only 60 bolls and squares per plot. This period of shading was followed by a severe drought which caused excessive shedding of bolls on all plots and no significant differences between the shaded and check plots were found in the yield of seed cotton at time of harvest. One of the outstanding results of the brief shading was the much more abundant foliage on these plants throughout the period of drought (see fig. 15). This would indicate a marked effect of the shading in addition to the dropping of forms. Possibly new vegetative processes were initiated by the shading that was maintained during the drought period. Such a response suggests the possible serious effects (even under favorable growing conditions) that might follow a period of cloudy weather of sufficiently low light intensity to cause excessive shedding.

Age of Plants and Fruiting Forms in Relation to Shedding

In the summer of 1943, a group of sixty cotton plants comprised of six plants of each of ten varieties growing in 2-gal. jars of soil was divided into six groups of ten plants (one plant of each variety: Stoneville 2B, Rogers Acala No. 111, A. D. Mebane Estate, Deltapine 14, Roldo Rowden, Qualla, Coker 4-in-1, Washington, Lone Star, and Half and Half). One of these groups was kept outdoors continuously as a check. The other groups were placed in a laboratory room (noonday light intensity 50-75 f.c.) for four days, in a consecutive order as shown in table 8. The first group had been in flower about ten days when placed indoors (on July 10). The different types of forms (small squares, large squares, flowers, small bolls, and large bolls) that were shed were recorded separately each day. At the end of this 4-day treatment most of the fruiting forms had been shed from the plants, which were then returned to their former outdoor positions.

The plants that received no indoor shade produced the best yield of bolls and the highest percent-set and they also made the least vegetative growth (weight of stem and leaves) of all the groups. In general, the groups that received the shade treatment early in the fruiting period were adversely affected to a greater extent, in regard to final crop of bolls and percent-set figures, than the groups that were shaded later. An exception to this conclusion may be noted in the second group of plants (shaded July 10-14) which showed a better fruiting record than the third or fourth groups. This was due for the most part to the fact that new squares

Table 8. Effect of age of plant on the response of cotton to a 4-day period of shade. Average of 10 plants; planted May 14, 1943

Date of shade on different groups	Height cm.	Weight of plant g.	Number of bolls set	Number of bolls shed	Weight of bolls g.	Percent set
No shade	69	148	9	19	158	32
July 10-14	87	258	6	29	96	17
July 14-18	103	319	1	24	14	4
July 18-22	92	213	3	22	40	12
July 25-29	76	163	5	22	81	19
July 29-Aug. 2	81	177	7	25	133	22
Diff. req. at 5%	12.8	99.4	2.7	5.2	14.5	....

developed on the plants following the shading of this early group and these had sufficient time to produce bolls large enough to be harvested on August 20. The most serious effects from shade were obtained in the second shaded group (July 14-18), as shown by the decrease in fruiting and by the increase in vegetative growth. Later treatments on other plants of the same age produced effects correspondingly less damaging to the fruiting processes.

The data in table 9 show the relative susceptibility of squares of different ages, flowers, and bolls of different ages to shedding caused by unfavorable light conditions. In keeping with many recorded observations of shedding under field conditions, the small bolls (just after flowering, fig. 1-D) were the first forms to be shed and the heaviest shedding of those young bolls took place on the second day following placement of the plants indoors. With the older plants (groups shaded later) it may be noted that a number of large squares and also of small squares were shed on the second day indoors. On the third day, the small bolls were again shed most severely by the first two groups. In case of the last three groups, the shedding of large squares (fig. 1-B) exceeded that of the small bolls and a few small squares were also shed (fig. 1-A) at this time. By the fourth day only a few small bolls and large squares remained on the plants and the large squares were more numerous than any other single type of fruiting form. At this time the small squares were shed in much greater abundance than on the two previous days. A few of the fair-sized bolls (about one-fourth grown, fig. 1-E) were shed on the third and fourth days under shade. In keeping with the frequent statement that shedding of upland cotton flowers rarely occurs, there were only a few forms with recently opened corollas shed and most of these were dropped on the fourth day. The last column in table 9 shows a greater amount of shedding of all ages of forms by the older plants (last three groups). The smaller number of forms shed by the first two shaded groups was associated with the smaller number of forms on the plants at that time. Practically all of the shedding in the check plants outdoors took place

Table 9. Relative susceptibility of fruiting forms of different ages (squares, flowers, and bolls) to shedding due to 4-day shade treatment. Same plants as in table 8. Figures given are totals for 10 plants.

Date of shade	Shed 2nd day					Shed 3rd day					Shed 4th day					Total for 3 days, all forms
	Small sqs.	Large sqs.	Flow-ers	Small bolls	Large bolls	Small sqs.	Large sqs.	Flow-ers	Small bolls	Large bolls	Small sqs.	Large sqs.	Flow-ers	Small bolls	Large bolls	
7/10–14				16			2		9	2	12	12	3	2	2	60
7/14–18				27			4		10	5	15	19		11	4	95
7/18–22	4	2	1	35		9	37		14	1	17	19	4	7	4	154
7/25–29	2	6		50	1	7	32	1	4	2	6	8		6	1	126
7/29–8/2	10	13		54		12	38		26		6	5	1	3	5	175
Total forms shed:																
per day	16	21	1	182	1	28	113	1	63	10	56	63	8	29	16	
3 days											100	197	10	274	27	

between August 2 and 20 which was after the treatment was applied to the last group and the forms shed were mostly small bolls.

This experiment indicates that young bolls, just after the flowers have dried up, are more sensitive to shedding following low-light-intensity treatment than fruiting forms of other ages. When light conditions become more unfavorable, however, other forms (squares, and larger bolls) may be shed abundantly. These results are in keeping with observations made during the different seasons in this work. During the summer, for example, few forms other than young bolls have been shed from the check plants in the experiments. Under greenhouse conditions during the fall, winter, or spring, however, there has appeared at times a tendency to shed a larger number of squares, especially very small squares five millimeters or less in diameter (see smallest square in fig. 1). This shedding of small squares was particularly marked in the soil plants grown during the winter, 1942-43. In this case, the average number of bolls (nine) per plant for ten varieties was rather low although the average percent-set was unusually high (53%) for that time of the year, with shedding data including only the young bolls. In many cases the entire growing point was shed along with the small square which resulted in a determinate type of growth on the fruiting branch. Sand-culture plants grown in the same greenhouse at the same time gave a comparable low yield (seven bolls per plant, average of eight plants each of ten varieties) but the 32 percent-set was correspondingly low, showing that more shedding of small bolls and large squares took place. It is believed that the nutritional differences between the soil and sand cultures, coupled with peculiar weather effects for that season, may have resulted in this unusual shedding of small forms by the soil-grown plants. Careful records were kept of the shedding of these small squares in the fall-winter and spring series 1943-44 for both soil and sand plants. Although considerable shedding of small squares took place (up to 10 or 15 per plant in some cases) it did not appear to affect the yields appreciably. All of the six varieties in the test shed similar numbers of these small forms, with the Half and Half variety showing a slightly higher rate of shedding than the others. This shedding mostly took place after a fair number of bolls had been set and, in actively-growing plants, new flower buds promptly appeared on the next node. However, the fact that the summer-series plants shed few small squares would indicate that some factor associated with the fall-spring conditions in the greenhouse was responsible for this loss of the smallest forms. Very few of these forms (not more than 3 to 5 per plant), however, were shed from the plants even under continuously low-light-intensity conditions in the summer series. Also, in the 1945 spring series, a few small and medium-sized squares were shed from all plants in an experiment, following a considerable amount of shedding of small bolls in response to cloudy weather from February 16 to 20. The plants were in an early fruiting stage at this time.

The results of an early shading test with twenty Stoneville 2B cotton plants during the late fall and early winter of 1943 is also of interest in connection with the shedding of small squares. The seed were planted on September 21 in 2-gal. jars of soil and the young plants were placed in the greenhouse on October 8. On November 20, five days before the first flower opened, ten of the plants were placed in a laboratory room for four days under low-light-intensity conditions. The first small squares (largest 15 mm.) abscised on November 22 and by the time the plants were replaced in the greenhouse they had each shed on the average 4 small squares and 2 large squares. On this date each of the check plants had 14 squares (2 mm. or more in diameter) and two of the check plants had a single flower. At the same time the shaded group averaged six attached squares per plant. During the two days following removal from the shade, these (shaded) plants each shed 2 squares, most of which were small. No further shedding was recorded until December 11 when shedding of a few (from all ten plants) small squares and small bolls took place on both the checks and the shaded plants. This initiation of shedding followed a period of eight cloudy days (December 3 to 10, inclusive). Following this period, all of the forms shed were small bolls and nearly all of them were from the check plants (6 per plant), with a total of only 3 small bolls shed from all ten of the shaded plants. At time of harvest on December 4, the shaded plants averaged 12 cm. taller than the checks (77 cm. vs. 65 cm.). The check plants each had 5 bolls that were past shedding stage and no other fruiting forms. There were no bolls on any of the shaded plants but the plants had an average of 7 squares of various sizes. This experiment shows the detrimental effect that the shedding of small squares due to low light intensity might have on the final set of cotton bolls, even though most of the shedding took place in advance of the so-called fruiting period. Also of interest is the fact that the shaded plants, even after the earlier heavy shedding, again started to shed at the same time as the check plants when unfavorable weather conditions occurred.

Close Spacing of Plants

As mentioned earlier, one of the methods used in this work for providing variations in the intensity of light reaching the experimental plants consisted in different spacings between the plants growing in jars of sand or soil. By this means, the foliage of the plants spaced closely together, so that the jars touched one another, was subjected to much more shading from adjacent plants than in cases where the jars were spaced about two feet apart. At the same time, other conditions such as temperature, atmospheric humidity, and the amount of available soil moisture and nutrients were practically identical for the close-spaced plants and the checks. In these experiments, the shading effect first became noticeable on the plants about the time of the appearance of the first blooms, when the leaves and branches of the close-spaced plants commenced to intermingle. As an indication of the density of shade provided by leaves of a cotton plant, it may be of interest to state that light-intensity readings taken among the lower leaves of plants on a greenhouse bench averaged around 600 f.c. while the direct sunlight intensity beside the bench was about 11,000 f.c. at noon on a clear day in April.

Data obtained in six separate experiments involving close-spacing of cotton plants are given in table 10. In the first three of these experiments an equal number of Stoneville 2B and Rogers Acala plants were used, while in the last three tests six varieties, Stoneville 2B, Rogers Acala, A. D. Mebane Estate, Deltapine 14, Qualla, and Half and Half were included in each experiment. The first, third, and fourth tests were conducted in the greenhouse during spring months (fig. 9), while the second, fifth, and sixth experiments were conducted outdoors in the summer. The data show a significant increase in height of plants in all of the close-

Table 10. Effects of close spacing of plants (in jars) on growth and fruiting of cotton. Average per plant.

Treatment	Number of plants	Height cm.	Wt. of leaves and stem g.	Number of blooms	Number of bolls set	Number of bolls shed	Weight of bolls g.	Per cent set
Planted January 27, 1942—2-gal. sand—2 varieties								
Check	16	137	475	41	20	21	....	49
Close spaced	16	150	445	31	14	17	....	45
Planted July 17, 1943—2-gal. sand—2 varieties								
Check	16	92	242	30	14	16	312	46
Close spaced	16	102	133	24	8	16	193	33
Planted January 21, 1944—3-gal. soil—2 varieties								
Check	32	93	269	28	12	16	253	43
Close spaced	32	105	250	22	8	14	187	36
Planted February 3, 1944—4-gal. soil—6 varieties								
Check	36	97	294	32	14	18	293	44
Close spaced	36	102	239	21	8	13	172	38
Planted April 5, 1944—2-gal. sand—6 varieties								
Check	12	69	208	26	14	12	318	54
Close spaced	12	79	209	27	12	15	265	44
Planted April 6, 1944—4-gal. soil—6 varieties								
Check	18	81	228	35	15	20	366	43
Close spaced	24	94	246	35	14	21	308	40

spacing treatments. Unlike the data previously shown for shaded plants, the results here do not show a greater fresh weight of leaves and stems due to the close spacing. In some cases, somewhat fewer blooms per plant were produced under the close-spaced conditions. The differences shown in number of bolls set between the check and close-spaced plants are highly significant (1 percent level) in the first four experiments shown in table 10, but they are not significant in the last two experiments. The difference in the number of bolls shed was found to be statistically significant at the 5 percent level only in case of the first and fourth experiments reported in table 10. The fresh weights of bolls on the check plants differed to a highly significant degree from those of the close-spaced plants in the second, third, and fourth experiments. The boll-weight differences in case of the last two experiments in table 10 were not great enough to show significance upon analysis. Percent-set figures for the close-spaced plants were consistently lower than those for the checks in all of the experiments listed in this table, although the amount of difference was not great in any case. It may be noted that the effects of the close spacing in the last two experiments (table 10) are less striking than the results obtained in the first four tests. This difference was probably due to the fact that the last two experiments were conducted outdoors in early summer while the others were carried on either in the spring or late summer, when the general light conditions were somewhat less favorable than in early summer. The response of the July 17 planting resembled the spring series more closely than the early summer plants since blooming did not start until the middle of September and the fruiting period occurred at a less favorable time of the year as far as light conditions were concerned. It is evident that the effect of the steady shading from close spacing was less detrimental to the fruiting processes and also gave less impetus to vegetative growth than the single brief periods of heavier artificial shade in the experiments just described. In connection with these close-spacing experiments, it is of interest to note that Cook (13) records the dropping or poor development of young bolls from cotton plants that were crowded in the field.

On a percentage basis, the amount of reduction in fruiting associated with the close spacing was considerably greater in some varieties (Rogers Acala, A. D. Mebane Estate, and Qualla) than in the other varieties in the comparison (Stoneville 2B, Half and Half, and Deltapine 14). The fruiting index, for example, was reduced 63, 46, and 73 percent, respectively, for the first group of 3 varieties just mentioned; while the corresponding reductions for the second group of varieties, due to close spacing, were only 80, 89, and 84 percent, respectively. Upon analysis of the data, no positive evidence of interaction between varieties and the close-spacing treatment was found.

EFFECTS OF VARIATIONS IN SOIL MOISTURE

Inadequate water supply to the cotton plant has been recognized for some time as a contributing factor to excessive shedding and impairment of yield. However, it was considered advisable to conduct several experiments on wilting of plants to varying degrees for the purpose of comparing wilting effects with those of low light intensity, in regard to the severity of shedding. Other experiments have been made in which the effects of wilting upon the uptake or utilization of available nitrogen were studied in relation to fruiting and shedding in cotton.

Relatively Brief Periods of Wilting

In the fall and early winter, 1939, an experiment was completed in which forty cotton plants (var. Startex) were grown in sand in four different sizes of containers, six-inch flower pots, and 1-, 2-, and 3-gal. jars. Approximately 2 quarts of nutrient solution were supplied daily to each plant by a slow drip-culture method at such a rate that the solution was continuously supplied throughout the forenoon. During the afternoon the plants were forced to draw upon the moisture reserve in the container which in the two smaller sizes was usually insufficient to prevent wilting on a bright day. The wilted plants were allowed to remain in that condition for about one hour before the sand was flushed with plain water. Late in the afternoon the sand in all of the containers was flushed with water. In this manner an attempt was made to provide all of the plants with approximately similar amounts of nutrients, regardless of the size of the container.

At the conclusion of the experiment, the average heights of the plants in the six-inch pots, 1-, 2-, and 3-gal. jars, were 90, 110, 121, and 124 cm., respectively. The fresh weights of the plants without the bolls were 151, 215, 225, and 257 g. in the same order. In spite of these marked differences in size of plants there was but little difference in number of bolls per plant (4, 6, 5, and 6, respectively) or in the percent-set (21, 28, 33 and 28 percent, respectively). Although the lowest percent-set occurred with the smallest containers (six-inch pots), the difference between the 1-gal. jars and the 2- or 3-gal. jars was not significant even though the plants in the 1-gal. containers often became wilted in the afternoon. It seemed, therefore, that the rather frequent wilting of the plants in the small containers for short periods of time was not sufficient to cause marked shedding of fruiting forms or serious decreases in the number of bolls set per plant.

The above experiment was repeated in the spring of 1940 using 105 plants and three sizes of containers, 1-, 2-, and 3-gal. jars. Similar results were obtained except that the plants showed better fruiting than in the fall. For each of the three sizes of containers the results were: number of bolls, 12, 13, and 12; and percent-set, 44, 40, and 35 percent, respectively. In this test, the plants in the smallest containers, although wilted for a period in the afternoon practically every day during the fruiting period, produced as many bolls as the plants in the larger containers and these same plants showed a slightly better boll-retention percentage.

In the summer of 1941, two groups, each containing eight Rogers Acala plants, were wilted on two occasions for two days at a time, during the fruiting period. The two periods of wilting for one group were imposed soon after the first blooms had appeared. The other group was wilted after the second and third week following flowering. There was a reduction in size of the early-wilted group of plants and both of these groups gave a somewhat smaller number of bolls per plant than the checks. The data for this experiment were as follows: for the checks, fresh weight per plant—390 g., number of bolls—24, and percent-set—56; for the plants wilted early, fresh weight—323 g., 21 bolls, and 59 percent-set; and for the late-wilted plants, fresh weight—380 g., number of bolls set—22, and percent-set—54.

The results of three additional experiments on the effects of frequent periods of wilting, for a few hours at a time, on growth and fruiting of cotton plants are shown in the first three sections of table 11. In the first two of these tests, Stoneville 2B plants were grown in sand culture and the treated plants were wilted for about two hours in the afternoon beginning soon after blossoming had commenced. Longer periods of wilting in sand culture are difficult to maintain owing to injury to the plant that may occur from excessive drying of the sand. As may be seen in these data, these short-period wilting treatments again caused apparent reductions in vegetative growth, height, and weight (difference highly significant in the second experiment) of plants, and reductions (significant at 5 percent in the first and second experiments) in fresh weight of the bolls. The differences in number of bolls set were relatively small, although significant in the second test, and the percent-set figures were similar for the checks and wilted plants.

In the third experiment, Stoneville 2B and Rogers Acala plants were grown in soil during the late summer, 1944, and part of the plants were wilted for a period of three or four hours just before each watering. During clear weather, this treatment usually resulted in wilting of the plants at least once every other day. The results of this test are given in the third section of table 11 and the differences obtained from the treatments are similar to those discussed above. There was a highly significant reduction in vegetative growth, with no corresponding decrease in number of bolls, weight of bolls, or in the percentage of bolls set. In this case, the increase in the total number of forms shed was significantly less (5 percent level) in the wilted plants than in the checks.

During the late summer of 1943, twenty Stoneville 2B plants were divided into four groups of five plants each and three of these groups were subjected to wilting for periods of different lengths when the first few bolls had set. The plants were kept outdoors except for the four-

Table 11. Effects of wilting on growth and fruiting processes in cotton. Average per plant.

Treatment	Number of plants	Height cm.	Weight of stem and leaves g.	Number of blooms	Number of bolls set	Number of bolls shed	Weight of bolls g.	Percent set
Planted May 12, 1942—2-gal. sand—1 variety								
Check	8	96	258	36	20	16	425	56
Wilted daily (after 7/18)	8	88	250	33	17	16	335	52
Planted June 24, 1944—2-gal. sand—1 variety								
Check	8	84	268	40	19	21	410	48
Wilted daily (after 8/22)	8	80	218	34	15	19	321	44
Planted June 26, 1944—4-gal. soil—2 varieties								
Check	8	92	313	42	15	27	384	36
Wilted before each watering	8	84	243	38	16	22	334	42
Planted July 17, 1943—3-gal. soil—1 variety								
Check	5	89	194	30	10	20	226	33
Wilted 2 days, 9/21–23	5	87	194	27	10	17	242	37
Wilted 3 days, 9/21–24	5	79	168	26	9	17	206	35
Wilted 4 days, 9/21–25	5	76	148	23	4	19	88	17
Planted December 5, 1944—4-gal. soil—10 varieties								
Check	70	93	231	32	13	19	272	41
Wilted 5 days, 3/1–6	70	90	253	31	10	21	222	32

day period (September 23 to 27) when they were all placed in a greenhouse in order to prevent interruptions in wilting due to rain. During the wilting treatment, the plants often became extremely wilted. They were maintained in a wilted condition for the desired length of time by light waterings at certain intervals.

Shedding curves for these plants, fig. 16-A, show that the wilting treatments caused an early loss of fruiting forms. The increase in shedding was noticeable on the third day following the start of the treatment and the highest peaks in the curves are associated with the three- and four-day treatments. With the exception of the two-day wilting treatment, there was but little shedding following these early effects, as compared with the later high rate of shedding for the check plants. Data on this experiment are shown in the fourth section of table 11. The

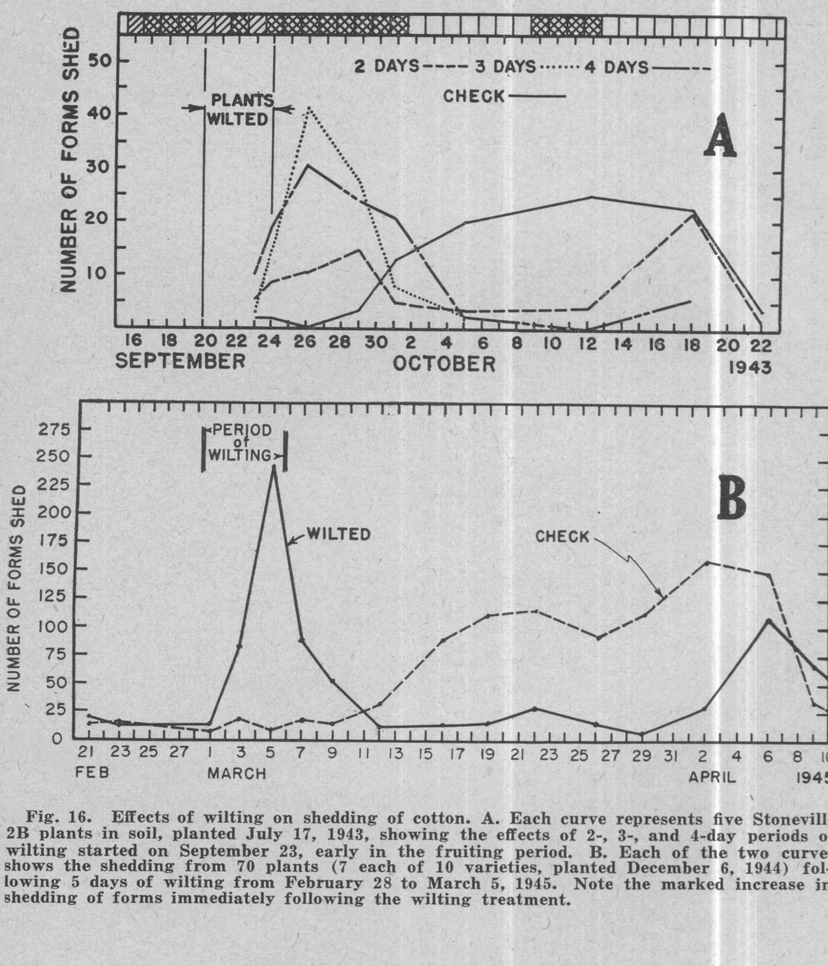


Fig. 16. Effects of wilting on shedding of cotton. A. Each curve represents five Stoneville 2B plants in soil, planted July 17, 1943, showing the effects of 2-, 3-, and 4-day periods of wilting started on September 23, early in the fruiting period. B. Each of the two curves shows the shedding from 70 plants (7 each of 10 varieties, planted December 6, 1944) following 5 days of wilting from February 28 to March 5, 1945. Note the marked increase in shedding of forms immediately following the wilting treatment.

reduction in vegetative growth, noted also in the previous wilting tests, is again apparent in the averages for the height and fresh weight of the wilted plants, although no significant difference between the plant weights was found by statistical analysis. In addition, the 4-day wilting caused a highly significant reduction in both the number and weight of bolls. The percent-set figure for this longest wilting treatment was exceptionally low.

A series of 140 cotton plants, including 14 plants of each of the ten varieties used in the seasonal studies (table 3), were raised in the greenhouse during the spring of 1945 for the purpose of testing the relative effects of a period of wilting on fruiting and vegetative behavior. Beginning on March 1, water was withheld for 5 days from seven plants of each variety, about two weeks after the first blooms appeared. The weather on these days was for the most part clear and, with the exception of March 3 when some of the wilted plants recovered from visible wilting, the plants were kept in a wilted condition by light waterings until March 6. After this single 5-day period of wilting both the check and wilted plants were given the usual, adequate waterings up to time of harvest.

In order to ascertain any possible skrinkage in stem tissues as a result of the wilting of the plants, the diameter of the stem of each plant was measured on March 1 with a micrometer caliper. The same measurements were taken again on March 6 as close as possible to the same points on the stems. As a result, it was found that 53 of the 70 check plants had increased measurably, 14 showed no change, and two of the measurements showed a decrease in diameter during the five-day period. Of the 70 wilted plants, however, 43 showed a definite decrease, 8 showed an increase, and 19 had not changed in diameter during the same period. This would indicate a shrinkage of the stem tissues had taken place during the period of water stress in the plants. Lloyd (38) found a similar skrinking of both stems and leaves of cotton on days of ordinary bright sunshine.

The shedding curves for this experiment are shown in fig. 16-B where a sharp peak of shedding occurred during the last day or two of the wilting treatment. This was followed for some time by a lower-than-normal shedding rate until a small peak in the curve for the wilted plants occurred just before harvest. The data for the two groups of plants are shown in the last section of table 11, with the ten varieties averaged together for each treatment. A highly significant reduction in number and weight of bolls was found to result from the single wilting treatment. Also a slight increase (significant at 5 percent) in the average fresh weight of the above-ground parts of the plants (without bolls) was found in the wilted plants. A difference of 9 percent was found in the percent-set figures.

As in the case of the close-spacing, the varieties used in this experiment showed considerable variation to the wilting treatment on a percent-reduction basis in regard to the data on fruiting. Likewise, however, no significant interaction was found between varieties and the wilting treatment and the data showing the varietal differences found are not presented. On the percentage-of-check performance basis, the Deltapine 14, Half and Half, Roldo Rowden, Lone Star, and Rogers Acala varieties were less seriously affected, in fruiting activities, by the wilting, than the other varieties tested in this experiment (Coker 4-in-1, Stoneville 2B, Qualla, A. D. Mebane Estate, and Washington). The ratios (wilted plant : check plant) for the fruiting index were 100, 91, 69, 79, 73, 77, 71, 64, 67, and 58 percent, respectively, for the ten varieties in the order named above for the two groups.

Variations in Soil Moisture and Nitrogen

The first of a series of experiments to study the effects of variations in levels of soil-moisture and available nitrogen on cotton fruiting and shedding was set up in the summer of 1941. Twenty-four 4-gal. jars of soil were planted on June 14 with the Rogers Acala variety and the first blooms appeared on these plants on July 22. On July 31, half of the plants were given the first of a series of wilting treatments by allowing the plants to remain in a wilted condition for three to four hours before each watering. Each of these two lots of plants were then divided into two additional groups (making four groups of six plants each) and each plant in two of these groups (one wilted and one nonwilted) was given extra nitrogen by adding ten grams of ammonium sulphate to the surface of the soil on August 8 and again on August 29. The plants were harvested on September 23. At this time, the average nonwilted plants with the extra nitrogen had the greatest fresh weight (475 g.), the largest number of bolls (30 per plant), and the highest percent-set (52 percent). There was but little difference between the other three groups either in vegetative growth or in fruiting. The fresh weight of the wilted plants with extra nitrogen showed the closest approach to the nonwilted-plus-nitrogen plants, in the data taken. For these three groups the data were as follows:

Nonwilted, without extra nitrogen, fresh weight of plants—194 g., number of bolls—10, percent-set—42;

Wilted plants plus nitrogen, weight of plants—254 g., number of bolls—11, percent-set—44;

Wilted plants without extra nitrogen, weight of plants—145 g., number of bolls—7, percent-set—39.

It may be seen from these figures that the adequate water supply was as important as the extra nitrogen in obtaining a good yield of bolls and only where ample water was present to prevent wilting at all times did the high nitrogen applications result in an increase in number of bolls. The high-nitrogen plants that were wilted, however, had a darker green color than those similarly wilted and lacking the extra nitrogen and it was in this group (extra nitrogen) that the above-noted increase in fresh weight from the nitrogen occurred in spite of the frequent wiltings.

Table 12. Effects of experimental variations in soil moisture, with and without extra applications of nitrogen, on growth and fruiting of cotton plants. Average per plant.

Treatment	Number of plants	Height cm.		Weight of stem and leaves g.		Number of bolls set		Number of bolls shed		Weight of bolls per plant g.		Percent set	
		−N	+N	−N	+N	−N	+N	−N	+N	−N	+N	−N	+N
Planted October 1, 1941—4-gal. soil—Stoneville 2B													
Check	5	75	79	208	292	11	14	13	13	......	......	46	52
1-1/2 lb. above wilting[1]	5	62	57	154	161	6	7	7	6	......	......	46	54
Wilted[2]	5	62	55	119	114	4	4	7	6	......	......	36	40
Planted February 12, 1942—4-gal. soil—Deltapine 14													
Check	3	98	105	192	308	14	18	15	6	......	......	48	75
4 lb. above wilting[1]	3	78	87	148	192	10	14	10	11	......	......	50	56
2 lb. above wilting[1]	3	82	77	155	145	12	11	10	8	......	......	55	58
Wilted[2]	3	70	63	100	95	8	8	6	7	......	......	57	53
Planted April 29, 1942—4-gal. soil—3 varieties													
Check	6	70	86	147	288	8	17	12	23	147	403	40	43
6 lb. above wilting[1]	6	66	73	140	300	8	15	11	19	148	327	42	44
3 lb. above wilting[1]	6	63	73	104	236	7	13	12	13	132	296	37	50
Wilted[2]	6	66	63	102	155	8	10	13	9	145	230	38	53
Planted November 18, 1942—2-gal. soil—2 varieties													
Check	4	63	72	71	123	3	5	6	8	52	83	33	38
2 lb. above wilting[1]	4	58	63	56	96	3	5	4	6	48	83	43	45
1 lb. above wilting[1]	4	50	53	50	71	3	3	4	5	46	50	43	38
Wilted (late)[3]	4	64	68	59	96	3	3	7	11	43	42	30	21

[1]The plants were weighed daily and enough water added to make the total weight this amount above the wilting-point weight.
[2]Plants were wilted for 3 or 4 hours before each watering, beginning about time of first bloom.
[3]Wilting treatment started February 19, 1943. Plants harvested March 11.

A somewhat similar experiment was conducted in the fall of 1941 with Stoneville 2B plants in 4-gal. jars of soil (planted October 1). In addition to the check (abundantly-watered) and a wilted group (5 plants each), another group of 5 plants was given sufficient water each day to bring the weight of the plant and container to a certain weight (1½ lb. above wilting point at time of first bloom). The treatments were commenced on November 15 and the extra nitrogen (10 g. ammonium sulphate per plant) was added on December 10. The data were taken January 22 and they are shown in the first part of table 12.

Additional experiments dealing with the availability of nitrogen in soil under varying moisture conditions and the coincident effects on fruiting and growth are also listed in table 12. In most of the cases the check plants (watered frequently enough to prevent wilting at all times) were compared with plants that were wilted before each watering and also with intermediate treatments consisting of the addition of sufficient water to bring the container and plant to a given weight daily. It may be seen in this table that the extra nitrogen was effective in increasing the number of bolls per plant only under the favorable soil moisture conditions. In two of the four experiments where the data are given, an increase was also found in weight of bolls due to the nitrogen and this effect was noticeable even in the drier soil. Vegetative growth in every case was inhibited by all of the drought treatments that were started early in the fruiting period, as shown by the height measurements and fresh weights of stems and leaves at time of harvest.

In table 12, the percent-set figures within a given experiment are considerably alike regardless of the treatments involved. These relatively similar percentages are apparent even in cases where the treatment produced marked differences in vegetative growth or in yield of bolls. Exceptions to this uniformity in percent-set figures occur in two cases: In the check high nitrogen plants in the second experiment, the percent of bolls set is high (75 percent). This may be attributed to the active vegetative growth of these plants up to the time of harvest and to a slight delay in blooming. In the other case, the wilting treatment was not applied until a large plant had developed with the extra nitrogen, and the treatment was severe enough to cause considerable shedding which resulted in the low percent-set (21 percent) for the high-nitrogen plants. A condition similar to this is shown in fig. 17. In general, the results in table 12 compare favorably with those in table 11 where somewhat similar wilting treatments were applied.

Excessive Soil Moisture

In the late summer, 1943, a study was made of the effects of waterlogging of soil on the shedding of cotton forms. Thirty-two plants of the Stoneville 2B variety, planted July 17, in 3-gal. jars of soil, were separated into four groups of 8 plants each on September 16 and the following treatments were started on that date:

Fig. 17. Effects of several-hours' wilting every other day on Deltapine 14 cotton plants in soil with high nitrogen content. In this case the wilting was started (plant on right) when the plants were over 2 months old, as the first bolls were approaching maturity. The heavier shedding that has occurred on the wilted plant is apparent in the lower right picture (leaves removed). This represents one of the few intermittent wilting treatments that resulted in increased shedding.

(*a*) Checks, usual watering at first signs of wilting.

(*b*) Two waterings of soil each day, to maintain a saturated condition of the soil.

(*c*) Drainage hole in bottom of jar closed and moisture content of soil maintained at a high level by daily watering.

(*d*) Jars (with drainage hole open) placed in a saucer which was kept filled with water.

During the first eight days after the treatments were applied, the plants in the jars with no drainage (*c*) wilted conspicuously and five of these eight plants died between the fifth and eighth day. In this same period many of the (*d*) plants standing in saucers of water also wilted but none of these were dead on September 24. A few of the plants that were watered twice daily (*b*) wilted for two or three days towards the end of this 8-day period.

In spite of the continued wilting to which many of the plants had been subjected, there was no shedding of any fruiting forms up to September 24. At this time a period of cloudy weather with occasional rain began and lasted until October 2, during which the living plants in all treatments apparently recovered from any previous wilting and the foliage remained turgid. On September 28, a large number of forms were recorded as shed from all of the living plants, with a significantly larger proportion of these from the *d* plants standing in water than from either the checks or the plants watered twice daily. Following clearing of the weather on October 2, many of the treated plants showed severe wilting symptoms. During the following two weeks, shedding of forms, mostly in the young boll stage, proceeded at a fairly high rate in all of the living plants. In this period, also, the three remaining plants in the *c* treatment died, together with four of the *d* plants standing in water. Only one plant died in the *b*-treatment group and this was recorded as dead on October 5. The final totals of shedding counts for the eight plants in each of the four groups up to the time of harvest (October 18) were as follows: Check (*a*) 31 small squares, 20 large squares and 67 bolls; watered twice daily (*b*) 34 small squares, 41 large squares, and 64 bolls; no drainage (*c*) 9 small squares, 11 large squares, and 55 bolls; and jars standing in water (*d*) 57 small squares, 48 large squares, and 82 bolls. The total number of large bolls on the plants at time of harvest, per group of eight plants, were 50, 51, 12, and 24 for the checks and each of the three treatments (*a*-*d*), respectively. In these data, all large bolls (past the shedding stage) were recorded for all plants including those that had died during the course of the experiment.

It is of interest to note, in the data just given, that the *d* plants, standing in water, showed an increased shedding rate and a smaller number of bolls retained, as compared with the checks. This increase in shedding was not apparent for the plants that received excessive watering (twice daily) nor for the *c* plants in jars without drainage, most of which died early. It seems therefore that some of the high soil moisture treatments may have predisposed the plants to shed a few more forms than normal. In this experiment, however, many of the forms on the plants that died were not shed but remained attached to the branches even after the leaves were shed. In such cases the plants may have been killed by drowning of the roots before formation of the abscission layer had become complete. The heaviest shedding in the early part of this test was also associated with the earliest wilting symptoms following the water-logging treatments. Albert and Armstrong (2) have reported increased shedding of small squares following flooding of the soil. In this connection, it may be of interest that certain large plants in the 1942-1943 fall-winter series growing in a fine sand that did not allow proper drainage showed severe wilting on clear days following periods of cloudy weather in December. In no case, however, was any excessive shedding recorded following this wilting which in some cases extended over a period of two days or more. The percent-set figures for these plants were similar to those of the same varieties in the 1943 fall series when a coarser sand was used and the wilting effects following cloudy days were not as marked.

EFFECTS OF TEMPERATURE

Since high air temperatures are considered as contributory to excessive shedding in cotton, a few experiments were made to study the effects of temperature as a factor in shedding and to compare temperature effects with those of light, under similar cultural conditions. Some of the studies of the growth and fruiting of cotton under high temperature conditions were made by growing the plants in an unshaded greenhouse during the summer. On clear days in the summer, the temperature in the greenhouse without shades was about eight to twelve degrees higher than outdoors, as shown in fig. 2-D. Maximum temperatures of from 105° F. to 115° F. were recorded under these conditions by a thermometer shaded by the foliage of the plants around noon on cloudless days. Also, one test was made in which cotton plants were removed from a heated to a nonheated greenhouse for several days in the winter to obtain a low-temperature effect.

High Temperature Conditions

Extended periods of high daily temperature. The first evidence in this work of the unfavorable effects of temperatures above 100° F. on cotton fruiting was obtained from a group of sixteen Rogers Acala plants in 2-gal. jars of sand that were started in an unshaded greenhouse in April and kept there until time of harvest, July 25, 1941. These plants made excessive vegetative growth and were much taller than check plants of the same age that were kept outdoors after May 30. On the average, the greenhouse plants produced 64 blooms and eleven mature bolls, giving 17 percent-set. The average outdoor check plant produced 41 blooms and

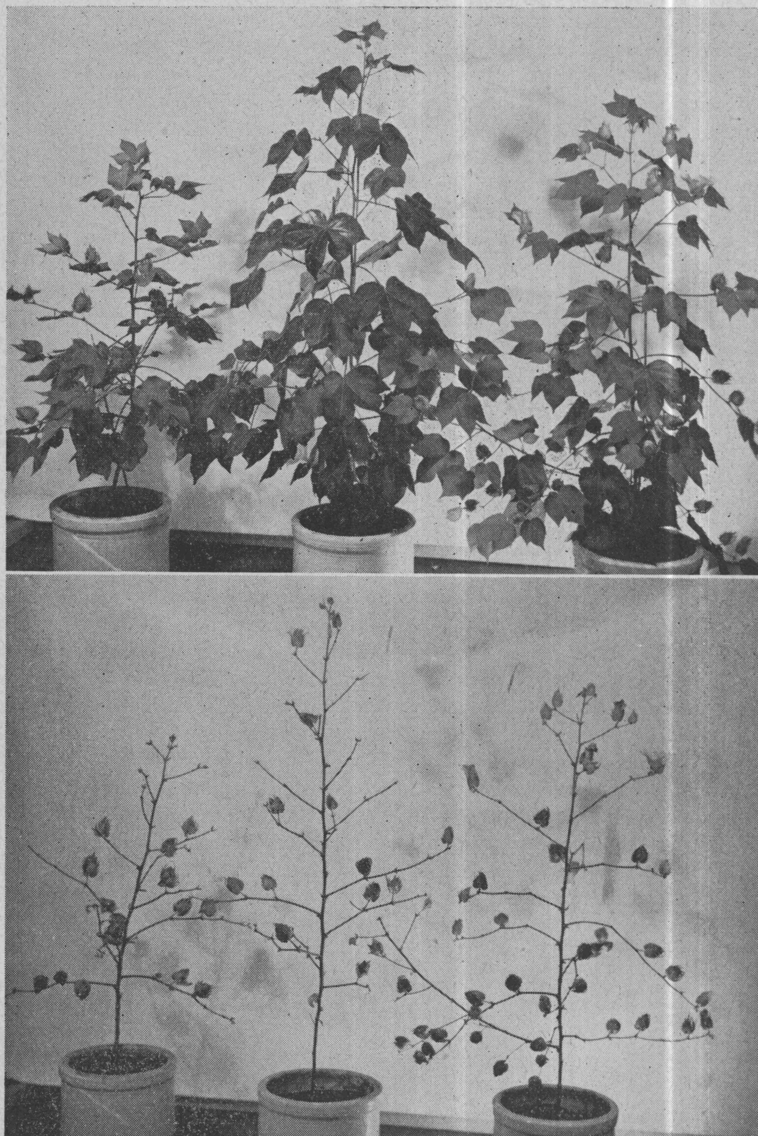


Fig 18. The cotton plant on the left was grown outdoors in the summer. The center plant was placed in a section of the greenhouse covered with roof shades, as soon as the first squares were full grown. At the same time (June 6), the plant on the right was placed in an unshaded part of the greenhouse. The photographs, taken August 2, show the increased vegetative growth of the greenhouse plants. The nonshaded greenhouse (high temperature) plant produced more bolls than either the comparable shaded plant or the check. The outdoor check plant produced the largest weight of bolls, however, and showed the highest percentage of bolls set.

24 bolls, or 56 percent set. A high shedding rate accompanied by low yield of bolls were outstanding effects of the high temperature prevalent in the greenhouse during the summer.

Another test similar to the one above was made during the summer of 1944 with cotton plants in 4-gal. jars of soil. Two groups totaling 36 plants, three plants each of six varieties (Stoneville 2B, A. D. Mebane Estate, Rogers Acala, Deltapine 14, Qualla, and Half and Half), were used. One group was kept in the greenhouse from June 6 until August 2 (time of harvest) and the other served as outdoor checks. The results are shown in the first part of table 13. As in the previous test, a higher shedding rate was found for the high-temperature plants. In this case, the difference in set of bolls, although only three per plant, was significant at the 5 percent level while the decrease in weight of bolls was highly significant. At the time of harvest, the average boll on the check plants weighed 23 grams while the average boll on the high-temperature plants was only 14 grams in weight. Analyses of the data show that the greater number of bolls shed under the high temperature conditions is highly significant. The increased vegetative growth (fig. 18) of the greenhouse plants is shown by the average weight of stem and leaves which is 20 percent greater (significant at 1 percent level) for the greenhouse group. This more active growth is associated with a significantly (at 1 percent level) larger number of blooms and a lower fruiting index figure for the plants under the high temperature conditions. In the shedding curve for the greenhouse plants (not shown) the young bolls were shed at a steady, high rate throughout the fruiting period while the outdoor plants showed a single peak coinciding with unusually high maximum daily temperatures outdoors (see fig. 19).

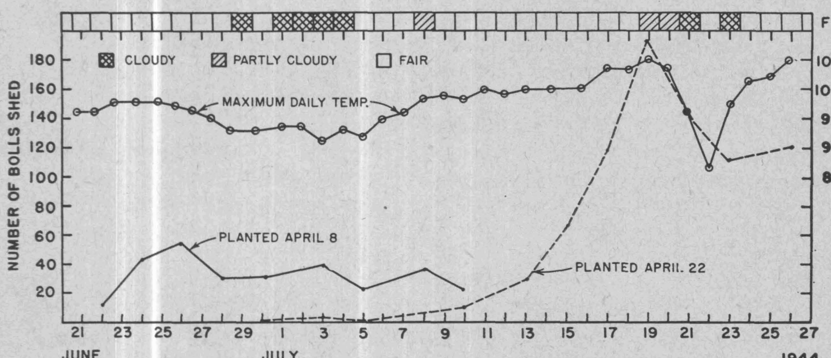


Fig. 19. The solid-line curve represents shedding from 48 cotton plants, Stoneville 2B variety, planted in 2-gal. jars of soil on April 8, 1944. The broken line shows the shedding from 42 plants (six varieties) planted in 4-gal. jars two weeks later. The weather during the period was mostly clear except for a few cloudy days early in July. Note the relatively steady rate of shedding for the older plants and the sharp peak for the later planting which occurred late in the fruiting period and apparently was associated with the high daily temperatures.

Table 13. Effects of high and low temperatures on fruiting of cotton plants. Average per plant.

Treatment	Number of plants	Height cm.	Weight of stem and leaves g.	Number of blooms	Number of bolls set	Number of bolls shed	Weight of bolls per plant g.	Percent set	Fruiting index
Planted April 6, 1944—4-gal. soil—6 varieties									
Check (outdoors)	18	81	228	35	15	20	344	43	1.5
High temperature greenhouse 6/6–8/2	18	97	273	52	18	34	251	35	.9
Planted June 24, 1944—2-gal. sand—Stoneville 2B									
Check	8	84	268	40	19	21	410	48	1.5
High temperature greenhouse 8/23–28	8	85	300	42	21	21	414	50	1.4
Planted September 16, 1943—4-gal. soil—Stoneville 2B									
Check (heated greenhouse)	10	53	....	15.3	5.6	9.7	....	37	....
In cold greenhouse 12/21–23 & 12/29–1/4	10	58	....	15.7	6.3	9.4	....	40	....

Brief period of high temperature. In the second part of table 13, the results of a late-summer experiment dealing with high temperature effects for a single brief period are shown. Eight Stoneville 2B plants were placed in the unshaded greenhouse for five days, during the early part of the fruiting period (August 23 to 28). A peak in the shading curve (not shown) with its apex on August 27 appeared for the plants in the greenhouse. This increased rate of shedding started on August 26 and lasted until August 31. There was practically no shedding from the check plants until August 31. In spite of this early shedding, the plants that were in the hot greenhouse for five days did not show any significant differences in any of the measurements as compared with the outdoor checks, although the figures for fresh weight of plants were slightly higher for the high temperature plants.

Further evidence of increased shedding tendency following exposure to high temperatures is shown in fig. 19 where the peak of shedding (in the curve for early summer plants in soil, planted April 22) occurred on July 19 following a week of hot weather in which the maximum daily temperatures were 100° F. or more outdoors. This was the only period of hot weather that has been of sufficient intensity to cause noticeably increased shedding from outdoor plants, in the course of the five-years' work here reported. Lloyd (38) recorded high shedding rates on a few occasions which he believed to be due to high temperature during a few previous days.

Evidence of varietal differences in response to high temperature. The data for the group planted on April 6, 1944 in the first section of table 13 represented a single group of eighteen plants made up of six varieties. By separating the varieties in this group, the resulting re-combination of data showed considerable variation in the relative effects of the high temperature treatment between the two groups. For example, one group of nine plants (Stoneville 2B, Deltapine 14, and Half and Half varieties) averaged 22 bolls set, 33 bolls shed, and 40 percent set. The other group (Rogers Acala, Mebane Estate, and Qualla) produced only 14 bolls set per plant, with 36 bolls shed, and 28 percent set. The average for both groups, as shown in table 13 was 18 bolls set per plant, with 34 bolls shed and 35 percent set. With the small number of plants of each variety per treatment, no significance was found in the interaction of varieties and the high temperature.

Effect of low temperatures on shedding. During the early winter, 1943, a group of 20 Stoneville 2B plants was set aside for a study of cold effects on boll shedding. On December 21, ten of these plants were placed in an unheated greenhouse. After two days, during which time a minimum night temperature of 45° F. was recorded, the plants were returned to the heated greenhouse on account of danger from freezing. They were placed in the cold greenhouse again on December 29 and remained there until January 4, 1944. During this second period, a low temperature of 38° F. was recorded on one night and some of the leaves showed injury from the cold. The plants were kept in the warm greenhouse until January 14 when data on fruiting were taken as shown in the last section of table 13. No significant difference was found in the set of bolls or shedding following the cold treatment. These results are in accord with field observations made in Texas Panhandle fields near mid-October 1941 when cotton with many green bolls showed no signs of excessive shedding following near-freezing temperatures on several previous nights. Ewing (23), however, noted an increase of shedding on one occasion in two years' work in Mississippi following low temperatures at night (54° to 56° F.) but there was also high evaporation at the same time and the effects of the low temperature were uncertain.

VARIATIONS IN CULTURAL PRACTICES

In order to obtain information as to the possible effects of nutritional differences that might arise in the various treatments, with the particular types of culture used in this work, experiments were conducted to ascertain the differences in fruiting that might follow certain definite variations in the amount of nitrogen and certain mineral elements available to the plants. Another purpose of these studies included comparison of the shedding rates associated with the various treatments. Although most of these data indicate but relatively small differences in shedding rates between the different treatments, marked differences in fruiting were obtained in many cases. With few exceptions, these nutrient variations were designed to simulate ordinary differences in soil fertility that might occur under field conditions, rather than to study the effects of deficiencies or excesses of these elements.

Varying Composition and Amount of Nutrient Solution

During the early part of the work on the shedding problem, a number of tests were made of the effects of changes in the ratios of the three important fertilizer elements (N, P, and K) on the set of cotton fruit. Nutrient solutions were used that included all possible combinations of two different levels of each of these three elements. In addition, a change in concentration of the nutrient solution, at a time about midway between the opening of the first flowers and the opening of the first mature bolls, was also included as a variable in the studies with sand-culture plants.

Results of two of these experiments are shown in table 14. The effects of increased nitrogen supply to the plants is very evident in the consistent increases both in vegetative growth and number of bolls set. These increases are apparent regardless of whether the extra nitrogen was supplied by increasing the amount of this element in the N-P-K ratio or by applying larger amounts of the complete nutrient solution by extra daily applications. Upon analysis of the data, significance at the 1 percent level was found for the figures on fresh weight of plants, num-

Table 14. Effects of variations in composition and amount of nutrient solution supplied to cotton plants, in sand culture, on vegetative growth and fruiting. Average per plant in all cases.

Composition[1] of nutrient solution		Fresh weight of plants g.	Number of bolls set	Number of bolls shed	Percent set
Up to middle of fruiting period	After middle of fruiting period				
Planted April 10, 1941—Early summer series—7 plants per treatment					
N-P-K	N-P-K	390	24	19	56
N-P-k	N-P-k	387	21	23	48
N-p-k	N-p-k	315	19	21	48
N-p-K	N-p-K	402	24	23	51
n-P-K	n-P-K	231	16	14	53
n-P-k	n-P-k	201	15	14	52
n-p-K	n-p-K	221	14	16	47
n-p-k	n-p-k	216	14	18	44
N-P-K, 2xda.[2]	N-P-K, 2xda.	554	33	18	65
n-p-k, 2xda.	n-p-k, 2xda.	465	28	22	56
Difference required[4] ..	....	62	2.3	4.4	....
Planted June 14, 1941—Late summer series—8 plants per treatment					
N-P-K	N-P-K	363	20	34	37
N-P-K	n-p-k	336	17	37	31
N-P-K	NN-P-K	405	26	33	44
NN-P-K	NN-P-K	535	27	40	40
n-p-k	n-p-k	169	9	18	33
n-p-k	N-P-K	247	14	21	40
N-P-K, 2xda.	N-P-K, 2xda.	601	31	32	49
N-P-K, 3xda.[3]	N-P-K, 3xda.	742	37	44	45
n-p-k, 2xda.	n-p-k, 2xda.	302	16	27	37
n-p-k, 3xda.	n-p-k, 3xda.	419	24	33	42
Difference required[4] ..	....	67	4.4	8	....

[1] N = 90 p.p.m. nitrogen P = 45 p.p.m. phosphorus K = 60 p.p.m. potassium
n = 30 p.p.m. " p = 15 p.p.m. " k = 20 p.p.m. "
NN = 180 p.p.m. "

[2] One liter of nutrient solution twice a day, 8 A. M. and 2 P. M.

[3] One liter of nutrient solution three times a day, 8 A. M., 12 N., and 2. P. M.

[4] Difference required for significance at 5 percent level.

ber of bolls set, and number of bolls shed in both experiments. The minimum differences required for significance at the 5 percent level are shown in the table for each of the two experiments.

In spite of wide variations in vegetative growth as shown by the fresh weights and also in the number of bolls per plant, there was but little difference between the different treatments in regard to the precentset. This indicates that increased vegetative growth, under these conditions, was not made at the expense of fruiting activities, but rather that the plants set fruit in proportion to their size. The slightly higher percent-set figures in case of the plants that received the highest amounts of nitrogen (either by extra daily nutrient applications or by stronger solutions) may have been due to a somewhat extended period of vegetative growth. In these cases, each of the high nitrogen plants had a few squares developing at time of harvest.

Another outstanding result shown in table 14 is the fact that changes in the concentration of the nutrient solution, during the fruiting period when there were several forms on each plant in the small-boll (susceptible to shedding) stage, did not seriously affect the percent-set. This shifting from one nutrient solution to another produced changes, in vegetative growth and in numbers of bolls set, associated with the amount of nitrogen supplied. When the change was made from the weak to the strong solution, the plants were larger and the number of bolls set greater than in case of the constant use of the weaker solution. Likewise, when the shift was from the strong to the weak solution, there was a decline in the growth and fruiting figures as compared with continued use of the more concentrated nutrient solution. Wadleigh (54) has shown that changing cotton plants from a nutrient solution of low osmotic concentration to a higher osmotic concentration, while maintaining the same high nitrogen level, may result in certain (relatively small) differences in shedding rates.

Of interest, also, in table 14 is the significant difference in number of bolls set between the low and high potassium contents in the nutrient solution, in the high-nitrogen plants of the early summer series. The low potassium, in case of both low and high phosphorus, produced a few less bolls than the high-potassium solution and a slightly smaller percent-set also accompanied these low-K treatments. The shedding curves (not shown) were similar for all of the treatments in both of these experiments and peaks occurred at practically the same time in all of the treatments.

The early summer experiment (first part of table 14), referred to above, was repeated during the fall and early winter. The seed were planted on September 4 and the plants were harvested on January 6-7, 1942. In keeping with results presented under "Seasonal Differences in Fruiting and Shedding", the set of fruit was much poorer and the percent-set lower than in the case of the summer plants. For the four treatments involving the high-nitrogen nutrient solutions, the average of thirty-two plants showed 6 bolls set per plant, 20 bolls shed, and a 23 percent-set. The corresponding figures for the same number of low-nitrogen-level plants were 5, 16, and 24, respectively. There was no apparent difference between the two groups in regard to size of plants. It may be seen, therefore, that the fruiting activities of both groups were very similar. At this season of the year, both high- and low-nitrogen plants set a small number of bolls considering the number of blooms produced. The negligible effects of the extra nitrogen for greenhouse plants during the fall and early winter may be due to the insufficient amounts of carbohydrates that are synthesized under the poor light conditions prevalent during these months which resulted in an increase in the vegetative growth. Much of the inorganic nitrogen taken up by the plants is supposed to be utilized through combination with carbohydrates into nitrogenous organic compounds.

A third comparison of these same nutrient solutions was made during the spring of 1942 with Stoneville 2B plants started on January 9. In this case, the four groups of plants (32 in all) with the high-nitrogen solutions had, on the average, 16 bolls set per plant, with 19 bolls shed, and a 46 percent set. The low nitrogen groups gave 11 bolls set, 13 bolls shed, and 46 percent set. These results resemble those of the summer plants more closely than the fall-grown plants, a condition found previously to be true for the spring series. The increase in number of bolls set due to the higher nitrogen level is apparent, although the percent-set figure is the same for both high- and low-nitrogen treatments.

In this experiment, there was a significant difference between the high- and low-phosphorus applications at both levels of nitrogen. For the high-nitrogen series, the 16 plants receiving high-phosphorus (45 p.p.m.) nutrient solution averaged 20 bolls set, 22 bolls shed, and 48 percent set; while the 16 low-phosphorus plants averaged 11 bolls set, 16 bolls shed, and 41 percent set. For the low-nitrogen series (16 plants), these same figures were 12, 13, and 48, respectively, for the high-phosphorus and 9, 13, and 41, respectively, for the low-phosphorus treatments. No ready explanation for these differences in phosphorus levels in this one test is apparent, although a different type of river sand was used in this case and its phosphorus-fixing properties may have been greater than that of other types of sand used in some of the other experiments.

Another summer series of plants was employed in a similar test in 1942. This group was made up of 56 plants, half of which were Stoneville 2B and the other half Deltapine 14. Seven different nutrient solutions were used involving three levels of each of the three major elements. The check treatment consisted of the middle level of all three major elements. In case of each of the other treatments, either the highest or lowest level of one of the elements was used in combination with the middle levels of the other two elements. The three levels of nitrogen consisted of 42, 84, and 168 p.p.m.; of phosphorus, 16, 32, and 64 p.p.m.; and of potassium, 20, 40, and 80 p.p.m. The results were very similar to those obtained with the Rogers Acala veriety in 1941. Increases were obtained in fresh weight of the stem and leaves, number of bolls set, and weight of bolls at harvest, in proportion to the amount of nitrogen in the nutrient solution. The variations in phosphorus or potassium did not produce any significant differences in any of the growth or fruiting responses. The percent-set figures varied from 46 in the low-nitrogen plants to 62 in the highest nitrogen level. Again, the narrow range in percent of bolls set is apparent in spite of widely different proportions of nutrient elements in the solutions used.

During the late summer of 1942, an additional experiment was carried out with 32 Stoneville 2B cotton plants, planted July 31 in 2-gal. jars of sand and harvested Ocetober 19. The plants were divided into four groups of eight plants each. One of these groups was supplied with a nutrient solution with medium concentrations of the three major elements as listed above. The other groups were supplied with three similar solutions in which the nitrogen, phosphorus, and potassium were used, respectively, at the highest level with the other two elements in each case remaining at the medium level. In this test, larger plants with about four more bolls (22 vs. 18) per plant and a significantly higher weight of bolls were obtained with all three of the treatments—high nitrogen, high phosphorus, and high potassium. Here, again the percent-set figures showed no marked variations, however, between treatments since the range was from 57 to 62 percent.

Comparison of One, Two, and Three Plants in Each Container

In order to ascertain any possible effect on fruiting or shedding that might be associated with an increase in the number of plants per container, a small test was made during the late summer, 1942, with Stoneville 2B plants in 2-gal. jars of sand. All of these jars were planted with several seed in each and after the seedlings had reached a fair size, all but one were removed from four jars, all but two from a second group of four jars, and three plants were allowed to remain in the third group. The average number of bolls produced by these plants per jar was: 18 (one plant), 19 (two plants), and 20 (three plants). The percent-set figures were 56, 53, and 46, respectively. There were no statistically significant differences between these groups.

OTHER EXPERIMENTS IN RELATION TO SHEDDING

During the course of these studies, several experiments have been completed, the results of which were either inconclusive in character or of minor importance in relation to the shedding problem. Some of these results seem of sufficient interest to include in this report.

Effects of "Chemical Hormones"

Since certain synthetic growth-promoting chemicals have been used to prevent dropping of fruits in certain horticultural crops, especially the preharvest drop of apples (24), trials were made of the effect of some of these chemicals on cotton boll-shedding. No apparent effects were found when 10 to 20 mg. of indole acetic, indole butyric, or naphthalene-acetic acids or naphthylacetamide were added six or eight times during the fruiting period to each liter of the nutrient solution applied to plants in sand culture. In the greenhouse, cotton plants sprayed with solutions containing 1000 p.p.m. of naphthalene acetic acid or levulinic acid showed marked epinasty (downward bending) of the leaf petioles within twenty-four hours, followed by excessive shedding of small squares. The epinasty and increased shedding were not apparent when the concentration of these two chemicals was reduced to 100 p.p.m.

During the summer of 1942, thirty-two Stoneville 2B cotton plants in 2-gal. jars of sand (planted May 12) were divided into four lots, three of which were sprayed eight times between June 24 and August 12 with solutions of 5 p.p.m. of the potassium salt of naphthalene acetic acid, 10 p.p.m. of levulinic acid, and 40 p.p.m. of levulinic acid, respectively. The plants were sprayed thoroughly at each application so that both surfaces of all leaves were wetted. Data taken on August 27 showed no significant difference in either growth or fruiting between the different treatments nor between the checks and the treatments. The average number of bolls per plant for each of the four groups varied between 21 and 23, while the percent-set figures varied from 55 to 60.

Fig. 20. Sections of cotton fruiting arms showing (center and lower left) three young bolls the stems of which were treated with naphthalene acetic acid in lanolin just before blooming. Abscission of the form was prevented but the boll dried up. In the lower right, a similarly treated boll is shown developing normally; above, untreated forms. Arrows show point of application of the "chemical hormone."

Another test with greenhouse plants, involving the treatment of the stems of squares, flowers, and young bolls with lanolin (wool fat) impregnated with naphthalene acetic acid at three different concentrations, was carried out in the spring of 1941. This work involved the treatment of 468 stems of fruiting forms on 30 Rogers Acala plants, including check treatments with plain lanolin, during the period from April 22 to May 8. With the 0.01 percent concentration of naphthalene acetic acid in lanolin, there was no difference in the amount of shedding resulting from the treatment. When the concentration was increased to 0.10 percent, the percentage of bolls set became smaller and still more serious shedding occurred with the 0.50 percent concentration. There was an indication that the forms treated during bloom were more adversely affected than the squares or small bolls. With the highest concentration of the chemical, many of the treated stems of the fruiting forms remained green and no abscission layer formed. The young boll did not develop in these cases, however, but dried up together with the calyx and remained on the plant, as shown in fig. 20.

Wetting of Open Flowers

As previously mentioned, other workers (38, 23) have found indications of increased shedding rates for young bolls whose flowers opened on days with showers in the forenoon. They concluded that rain destroyed the pollen in recently opened flowers and thereby prevented fertilization. Since these same effects have been noted in these studies and interpreted as due to low light-intensity effects, and since the same effects are found under greenhouse conditions, a test was made in which the flowers were wetted experimentally. This experiment was conducted during the summer, 1942, with sixteen plants of the Stoneville 2B variety planted May 12 in sand. The flowers on eight of the plants were sprayed thoroughly with water from an atomizer twice each day (morning and afternoon) on the day that they first opened (white flowers). The flower wetting was commenced on July 18 and the plants were harvested on August 28. At this time, the check plants had 19 bolls per plant and showed 54 percent-set. The plants with the sprayed blossoms had 17 bolls each with 46 percent-set. There were no statistically significant differences between the check and treated plants, in regard to number of bolls set or the number shed. In view of the fact that many of the sprayed blossoms retained water in the base of the corolla throughout the day, it seemed that this treatment should have equalled the effects of a heavy shower or a more prolonged rain, in deleterious effects on the pollen. Lloyd (38) reports that Orton and Duncan performed a similar experiment in 1907 and obtained a difference of only 6.61 in the percentage of bolls set and that they doubted the importance of rain on freshly opened flowers as a cause of shedding.

Although Lloyd (38) has reported the bursting of cotton pollen grains in water, there is some doubt as to the actual damage to the pollen from rains. Under the microscope, it has been observed that pollen from recently opened cotton flowers could be caused to burst readily by wetting. On the other hand, pollen was kept over night in a Petri dish, in which water was placed and condensation occurred on the glass, without damage to the grains. It is quite likely, therefore, that much of the pollen in an open flower might escape damage from wetting even during a rainy day.

Pruning and Related Treatments

Topping of plants. In the 1942 spring series of Stoneville 2B plants in sand culture, the top of the main stem was removed from eight plants at the time of the opening of the first blooms on March 14. This treatment was applied following suggested benefits from topping of plants in the field in southeastern Louisiana (4). Following topping, the treated plants made later vegetative growth mostly from the tips of fruiting branches. The topped plants (without bolls) averaged 431 g. each at time of harvest as compared with 474 g. for the check plants. The topped plants also had 15 bolls per plant and 45 percent-set while the check plants had 21 bolls and 48 percent-set. The average boll on the topped plants weighed 20 g. as compared with 17 g. each for the checks. Obviously, there was no marked advantage in this experiment from the topping treatment.

Removal of leaves from stem and fruiting branches. In the late fall of 1941, the stem leaves were removed from seven Rogers Acala plants when the first blooms appeared on the oldest fruiting branches. This treatment left the plants with foliage on the fruiting branches only. As a result, a reduction occurred in the number of bolls, from 6 on the check plants to 3 on the stem-defoliated plants, at time of harvest. The set of bolls was 25 percent for the treated plants and 21 percent for the checks. At the same time, the leaves were removed from the fruiting branches of seven other comparable plants. These branch-defoliated plants also had 3 bolls on the average at time of harvest and they showed a 16 percent-set. Along with this test, smaller numbers of Stoneville 2B plants were given each of the above treatments separately and in this case branch defoliation produced more bolls than were obtained from the nontreated plant.

On account of the indicated possible beneficial effect of fruiting-branch defoliation, another experiment was carried out in the late summer of 1942. Fourteen sand-culture, Stoneville 2B plants were divided into two lots and the fruiting branches of one lot were defoliated as described above. The data, taken on November 17, were very similar for the treated and nontreated plants. The defoliated plants produced 6 bolls, while the check plants produced 7 bolls. Bolls from each treatment averaged 21 grams apiece. Both lots showed 46 percent-set.

In the spring of 1945, all leaves and bolls past the shedding stage were removed from the fruiting branches of four sand-culture plants in the greenhouse. Many of the squares that remained produced full-sized bolls and no excessive shedding from these defoliated fruiting branches was noted.

Removal of squares from certain fruiting branches. The fruiting forms, consisting of various sizes of squares, were removed from the three lowest branches of five Rogers Acala plants in the summer of 1941. This treatment compelled the setting of the entire crop of bolls on the upper branches. Although the percent-set for plants with the forms removed was 58, compared with 50 percent for the checks, there was no significant difference between the number of bolls set—19 for the former and 18 bolls for the latter group of plants (checks).

A somewhat similar test was performed with sixteen Rogers Acala plants in the late summer, 1941. The squares were removed from all branches except six, spirally located along the stem, on eight of the plants. It was intended by this experiment to ascertain whether a cotton plant would set a given load of fruit even if the bolls had to be borne on a limited number of branches. At harvest, the plants with certain branches defruited had a fresh weight of 472 grams compared with 363 grams for the checks. The treated plants had only 11 bolls per plant but showed a percent-set of 69 whereas the checks had 20 bolls with a 37 percent-set. This experiment indicated that boll distribution over the entire cotton plant was necessary for the best yield of bolls. There was a marked improvement in the percentage of squares that produced mature bolls, however, in the plants with fruiting restricted to certain branches.

Removal of bracts from fruiting forms. Evidence of the independence of the cotton boll in relation to closely adjacent plant parts was obtained by removing the bracts (calyx) from immature forms at various stages of growth, from medium-sized squares to small bolls. Under greenhouse conditions in the spring of 1944, with Stoneville 2B and Coker 4-in-1 plants, this treatment did not change the percent-set of the treated forms as compared with those on which the calyx was allowed to remain. No measurements were made of boll-size in this test although the bolls that developed without the calyx appeared as large as those with the bracts removed.

Covering of Fruiting Forms

In the early fall of 1943, five lots of fourteen forms each, including squares, flowers, and small bolls, on a group of nine plants in the greenhouse were covered with five different materials: black cloth, black paper, white paper, thin cellophane, and tinfoil, respectively. A small piece of the material in each case was folded over the cotton form and tied around the stem of the form so as to form a hood. There were 42 squares, 11 flowers, and 17 small bolls covered, all on October 5. All forms not covered were removed. By October 10, only one of these forms had been shed. There were nine small bolls recorded as shed by October 14 and by the 23rd a total of 38 small bolls and 1 square had been shed. Thus, there remained 30 bolls on the 9 plants most of which were past the shedding stage. Among those remaining were 9 covered with black cloth, 7 with black paper, 5 with white paper, 5 with tinfoil, and 4 with cellophane.

Having obtained this indication that covering of immature cotton forms with opaque material would not always cause the form to be shed, a further trial of this sort using only tinfoil was made in the spring of 1944. Twenty-seven large squares, flowers, and small bolls selected at random on three Coker 4-in-1 cotton plants were covered on April 10. On May 19, fifteen of the twenty-seven forms covered had developed into large bolls. In some cases where the tinfoil was placed on large squares, the flowers had opened and the boll developed, all within this covering. The three plants had a total of 32 large bolls at this time and three comparable check plants had 33 bolls. It seemed therefore that the shedding rate was not increased by the tinfoil covering on the immature forms. It was also indicated that the shedding stimulus came from a general condition of the plant rather than arising from local conditions in the square or young boll. Further evidence was obtained in this connection when nine cotton plants were shaded for one week in October, 1943, except for certain fruiting branches which were allowed to project through holes in the black cloth covers. In this case, there was excessive shedding of many cotton forms on the branches in the sunlight and somewhat heavier shedding of forms on the shaded branches.

Comparison of black cloth and cellophane covers. In order to discover any causes of shedding, other than light intensity, that might be involved in the shading of cotton plants with cloth, a small test was made in the late summer of 1943 in which black cloth and cellophane covers were compared. Three Rogers Acala plants were covered individually with black cloth at 3:00 P. M. on September 7. At the same time, three comparable plants were covered with a cylinder of cellophane (Eastman acetate sheet, 0.01 inch) having a disc of the same material fastened loosely as a cover. There were also three check plants. The ventilation through all of the covers was so regulated that the temperature in each was two to four degrees higher than the outside temperature under sunlight conditions. The temperature in the shade of the leaves of the check plants at 4:00 P. M. on September 9 was 96° F., while under the black cloth and cellophane cover similar readings averaged 97° F. in both cases. The covers were kept in place over the plants continuously until 11:30 A. M. September 13. Some of the leaves that touched the cellophane were speckled with brownish spots, as if scorched. Twelve small bolls and 30 squares were shed from the three black-cloth-covered plants from September 13 to 17. During this same 6-day period, the three cellophane-covered plants shed only 2 small bolls in all and there was no shedding from the checks. The checks and the cellophane treated plants all shed a few small bolls from September 28 to October 7 but only two small bolls were shed by the black-cloth plants in this period. On the latter date, the check plants had 12 good-sized bolls per plant and showed 68 percent-set. The cellophane-covered plants had 7 bolls per plant and a 42 percent-set. Those under black cloth shade had only one boll per plant and these plants showed by far the poorest set (8 percent). This small-scale test indicated that the low-light-intensity effect of the black-cloth shade was the important factor in shedding under these conditions. The somewhat fewer bolls and lower percent-set for the cellophane-covered plants as compared with the checks may have been due to the slightly higher temperatures involved and to the leaf injury associated with the cellophane cover.

Mild Shade Treatments Followed by Clear Weather

In a few instances in the course of this study, the effects of shedding caused by experimental treatments have not been severe enough to cause significant differences in final yields of bolls, and in a few cases even beneficial effects of such treatments have been noted. For example, half of a series of forty-eight plants (made up of six varieties, Stoneville 2B, Coker 100 Str. 5, Rogers Acala, Deltapine 14, Mebane, and Delfos 531 B)

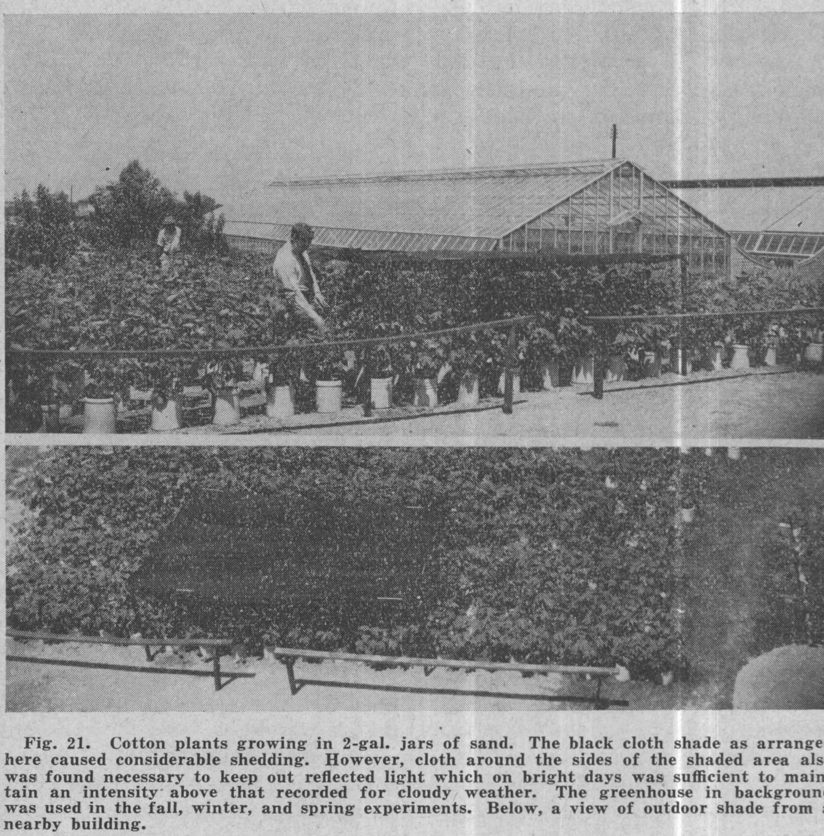


Fig. 21. Cotton plants growing in 2-gal. jars of sand. The black cloth shade as arranged here caused considerable shedding. However, cloth around the sides of the shaded area also was found necessary to keep out reflected light which on bright days was sufficient to maintain an intensity above that recorded for cloudy weather. The greenhouse in background was used in the fall, winter, and spring experiments. Below, a view of outdoor shade from a nearby building.

in 2-gal. jars of sand were shaded for two periods, June 24 to 27 and July 7 to 12, 1942. The shade consisted of a flat roof of black cloth just above the tops of the plants (fig. 21). There was no shade cloth around the sides of the group of shaded plants. Consequently, the light intensity from above under the center of the shade at noon on a clear day was about 400 f.c. With the target of the light meter pointed towards the open sides, however, intensities from three to six times this figure were obtained. Also during the second period of shade for five days, only about two and a half days were clear. Counts of forms that were shed during the first twenty-four hours following removal of the cloth after the second period of shade showed 6 bolls and 1 square to have been shed by the shaded plants, on the average, and 2 bolls and 1 square per plant from each of the checks. Only four cloudy days occurred between the removal of the last shade and the time of harvest, July 28. The data showed that there was but little difference between the checks (22 bolls and 47 percent-set) and the shaded plants (20 bolls and 43 percent-set). This difference was slight compared with the amount of shedding that had been found to result from the shading treatments.

Another case of this sort occurred during the summer 1944 series, when 48 plants (twenty-four each of Stoneville 2B and Rogers Acala) in 2-gal. jars of soil were divided into six groups and different shade treatments given to five of the groups by placing them in the shaded section of a greenhouse (light intensity about 2000 f.c. at noon) for various periods between August 2 and 10. The treatments resulted in marked shedding at the time. After the plants were replaced outdoors the weather remained mostly clear up to the time of harvest on August 21, when the check plants averaged 7 bolls per plant and the shaded plants varied between 7 and 9 bolls per plant. The percent-set for the checks was 35 while the five treatments varied from 37 to 45 percent-set. In regard to boll weights, however, the check plants produced the greatest total weight of bolls at time of harvest. The average weight per boll on the check plants was 23 grams while similar averages for the five treatments varied between 14 and 20 grams per boll. There was no significant difference between the fresh weights of the plants in the different groups at time of harvest.

Excessive Shedding by Plants with No Boll-Load

Early in June, 1944, eighteen 2-months old cotton plants (three each of six varieties) in 2-gal. jars of sand were placed inside an unshaded greenhouse. The sand mixture in which these plants were growing contained a too large proportion of fine particles and the plants suffered from wilting to a serious extent as the water requirements were high under these conditions. Only one of the plants died, however, and the others apparently became partially adjusted to these conditions. Excessive shedding of the fruiting forms occurred and on July 21 the number of (immature) bolls per plant varied from none to eight. At this time all bolls, flowers, and large squares were removed and the plants were returned outdoors.

It was intended that these plants should be used to furnish a number of small bolls for another test. The plants made a large amount of new growth and soon many new fruiting forms were developed on all of the plants. Of the 142 blooms that were tagged between July 25 and August 5, only 44 (31 percent) remained on the plants past the small-boll stage. Considering the fact that there were only two cloudy days (August 7 and 12) and two partly cloudy days (August 5 and 6) between July 25 and August 17, this percent-set is unusually low for plants outdoors in the summer. These particular plants, furthermore, had no maturing bolls to make a load on the plants at this time. Apparently, maintenance of the rapid growth, over a relatively long period following removal of the plants from the greenhouse, utilized most of the carbohydrates synthesized during this period.

QUANTITATIVE CARBOHYDRATE ANALYSES OF COTTON PLANTS UNDER VARIOUS CONDITIONS AND TREATMENTS

In the course of this study involving the effects of light, soil moisture, and temperature on shedding in cotton, considerable analytical work has been carried out to ascertain the variations in carbohydrate contents of plants subjected to the different treatments. Since all three of the above factors are known to affect photosynthesis and since variations in the shedding rate have often been attributed to variations in food reserves within the cotton plant, it has seemed necessary to measure the carbohydrates in cases where increased shedding rates were obtained. In this work, emphasis has been placed on the carbohydrate content of the leaves since a low-carbohydrate leaf content was found in preliminary tests to be correlated with increased shedding rates. However, other parts of both check and treated plants such as bolls, stem bark, tap-root bark, and tap-root woody tissue, were also analyzed. In practically all cases, the samples were selected to show the immediate effects on the plants within one to six days after initiation of the treatment. The analyses included only a determination of so-called "total carbohydrates" as shown by the reducing power of a hydrolyzed sample of dried and ground plant tissues.

In collecting the samples of leaves, care was taken to select at the same time like numbers (usually from 2 to 4 per plant) of comparable leaf blades from corresponding positions on treated and nontreated plants. The fresh weight of the leaf material was recorded and after drying for several hours at 70° to 80° C. in a forced-draft oven the samples were weighed again to obtain the dry weight. The larger veins were then removed and the dry leaf blades were ground in a hand mortar, after which the leaf powder was passed through a 40-mesh screen. One-gram samples of the dry powder were placed in 125 ml. Florence flasks to each of which 50 ml. of 2 percent hydrochloric acid were added and the flasks were placed in a boiling water bath for 30 minutes. The flasks and contents were then cooled, neutralized with sodium hydroxide (using the natural red color in the hydrolyzed solution as an indicator), cleared with neutral lead acetate and deleaded with potassium oxalate. The filtered, clear filtrate was made up to 100 ml. Ten-millileter aliquots of this extract were then added to 20 ml. of a modified Fehling's solution made up of equal parts of Solution A containing 12 grams per liter of copper sulphate and Solution B containing 44 grams of Rochelle salt and 16 grams of sodium hydroxide per liter. This mixture was heated in the boiling water bath for five minutes and the unreduced copper was determined by titrating the free iodine, obtained upon addition of potassium iodide, with a dilute solution (about 12 grams per liter) of sodium thiosulphate, using soluble starch solution to make the end-point more definite. Each supply of Fehling's solution was standardized with anhydrous dextrose. The total carbohydrate contents (as anhydrous dextrose) shown in the tables are expressed in percentages of dry weight of plant material.

This method is similar to a procedure previously used in a study (15) of the carbohydrate content of plants affected with certain virus diseases in which a 2-hour period of acid hydrolysis was employed. The method has provided a convenient and relatively quick estimation of the carbohydrate content of certain plant parts and it has been sensitive enough to give progressively higher readings for cotton leaves collected from morning to afternoon. The values reported in this study should not be considered as exact quantitative measurements of the absolute amount of the carbohydrates present. Using dry leaf powder from the same samples, the total carbohydrate content has been found considerably lower by this method than by an alcohol-extraction and diastase method.* The same relative differences between samples, however, were shown by either method. The carbohydrates measured in this way probably include the reducing sugars, disaccharides, starch, and dextrins, together with intermediate and closely related compounds.

Analyses of the bark and woody portion of the stem (sections about six inches in length taken just above the soil) were also made in cases of many treatments. These analyses were made as in the case of the leaf material except that the woody part of the stems was ground in a food-chopper with fine cutter before drying and the bark samples were ground finely in the food-chopper after drying. The bark and wood samples were not passed through the sieve. A few analyses of young bolls were also made, and in these cases the bolls were cut and dried and the part that could be finely ground in a mortar was sieved out for analysis. In all cases the samples under comparison were collected at the same time and those from treated and check plants were carried through the analytical procedure side by side under the same conditions.

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*The comparative analyses were made by Dr. D. R. Ergle.

Effects of Shade on Carbohydrate Content of Cotton Leaves and Stem Bark

Although it is well known that low light intensities are usually accompanied by reduced photosynthetic activities in plants, a number of analyses of shaded cotton plants have been made here in order to correlate shedding tendencies with variations in carbohydrate constituents of certain plant parts. Some plants are known to require only a certain fraction of ordinary sunlight for maximum photosynthesis (48). With cotton, insufficient work has been done along this line to state the light intensities necessary for highest carbohydrate production. However, certain analyses of leaves that had been shaded with white cloth, that reduced the sunlight intensity about 70 percent, have shown fairly consistent but slight reductions in total carbohydrates. Black cloth that allowed passage of about 4 percent of direct sunlight reduced the carbohydrates of the leaves to a much greater extent. The results of several analyses of cotton leaves that were shaded during the forenoon are shown in table 15 in comparison with analyses of leaves from nonshaded plants. Additional data involving the effects of low light intensities on carbohydrates in the leaves together with the results of analyses of the stem bark of the same plants are given in table 16. These samples were taken from cotton plants of different varieties and under various conditions as to time of year, temperature, age of plants, and shading treatment. These results indicate that reductions in light intensity from around 10,000 or 12,000 f.c. to about 3000 f.c. were associated with decreased carbohydrates in the leaves and stems. The most striking reductions in the carbohydrate content of both leaves and stems, however, was found in plants that had been subjected for a few days to light intensities of 500 f.c. or less. It may also be seen in these two tables that the carbohydrate

Table 15. Effect of white cloth and black cloth shade on carbohydrate content of cotton leaves

Date planted	Size of container	Sample taken		Material in sample	Percent total carbohydrates		
		Date	Hour C. S. T.		Check	White cloth	Black cloth
6/16/41	2-gal.	10/1	3 PM	12 leaves—4 plants[1]	6.5	4.4	4.1
6/16/41	2-gal.	10/6	1 PM	12 leaves—4 plants	4.7	5.1	2.6
5/20/42	1-gal.	7/13	1 PM	10 leaves—5 plants	8.6	9.7	5.9
5/20/42	1-gal.	7/13	4 PM	10 leaves—5 plants	12.0	11.3	7.6
5/20/42	1-gal.	7/14	1 PM	5 leaves—5 plants	8.6	7.6	4.9
5/20/42	1-gal.	7/14	4 PM	5 leaves—5 plants	8.9	7.2	5.7
1/21/44	3-gal.	4/27	3 PM	2 leaves—2 plants	7.3	4.1	2.6
				Average, all tests	8.1	7.1	4.8
				Percent of check	....	88	59

[1]Three leaves from each of 4 plants, making a total of 12 leaves per sample.

Sample taken		Shaded plants	Light intensity f.c.	Percent total carbohydrates			
				Leaves		Stem bark	
Date	Hour C. S. T.	Treatment		Check[1]	Shaded	Check[1]	Shaded
Planted 4/5/44, 2-gal. sand, 3 plants per treatment							
6/15/44	1 PM	In laboratory room 1 day	50	6.6	1.7	....	....
6/15/44	10 AM	In laboratory room 5 days	50	3.1	1.4	8.5	3.2
Planted 4/6/44, 4-gal. soil, 3 plants per treatment							
6/27/44	11 AM	In laboratory room 1 hour	50	4.8	4.5	....	....
6/29/44	10 AM	In laboratory room 2 days	50	5.3	1.5	....	....
7/ 1/44	10 AM	In laboratory room 4 days	50	5.4	1.1	....	....
7/ 3/44	10 AM[2]	In laboratory room 6 days	50	2.1	0.0	17.1	3.3
Planted 4/6/44, 4-gal. soil, 2 plants per treatment							
7/10/44	3 PM	Shaded greenhouse 5 days	2000	3.6	1.2	12.4	3.6
Planted 4/5/44, 2-gal. sand, 3 plants per treatment							
7/11/44	3 PM	Black cloth shade 1 day	500	3.8	2.2	8.6	4.6
7/12/44	3 PM	Black cloth shade 2 days	500	....	0.7	....	3.0
7/14/44	3 PM	Black cloth shade 4 days	500	2.2	1.0	9.4	4.2
7/16/44	3 PM	Black cloth shade 6 days	500	....	1.2	....	2.4
Planted 4/5/44, 2-gal. sand, 3 plants per treatment							
7/18/44	4 PM	Black cloth shade 1 day	500	2.0	0.0	9.2	3.4
7/19/44	4 PM	Black cloth shade 2 days	500	....	0.6	....	2.4
7/21/44	3 PM	Black cloth shade 4 days	500	3.6	0.0	4.4	2.0
7/24/44	9 AM	Black cloth shade 6 days	500	....	0.2	....	1.4
Planted 6/12/44, 1-gal. soil, 6 plants per treatment							
7/18/44	4 PM	Black cloth shade 1 day	500	9.1	2.5	11.1	6.8
7/18/44	4 PM	White cloth shade 1 day	3000	....	3.6	....	6.3
7/20/44	3 PM	Black cloth shade 2 days	500	....	1.5	....	5.9
7/20/44	3 PM	White cloth shade 2 days	3000	....	4.4	....	9.8
7/22/44	4 PM	Black cloth shade 4 days	500	7.7	1.8	12.4	4.5
7/22/44	4 PM	White cloth shade 4 days	3000	....	2.6	....	6.5

[1]Plants in normal sunlight (12,000–15,000 f.c. at noonday). [2]Cloudy day.

content of these plant parts may be lowered markedly within one day after application of the shade treatment. The results further indicate that mobile carbohydrate reserves may be quickly used by the cotton plant under low light intensity and they may require replacement regularly in order to maintain a normal level.

Analyses of plants under the continuously low-light-intensity conditions previously described showed lower carbohydrate contents in both the leaves and stem bark, both in the morning and afternoon samples, as compared with plants in direct sunlight.

Effects of Wilting on Carbohydrate Content of Leaves and Stem Bark

The results of carbohydrate analyses of plants that were subjected to various wilting treatments are given in table 17. Periods of wilting from 1 to 8 days were in practically all cases found to cause a marked reduction in the carbohydrate contents of the cotton leaves. This reduction was found to occur quickly following the treatments, as shown by the results of analyses at the end of the first day of wilting. In most cases, analyses of leaves wilted for two to four consecutive days showed still greater reductions in carbohydrate contents. The fourteen leaf samples from wilted plants showed (table 17) an average carbohydrate content 54 percent less than the average content of the nonwilted leaf samples. The only leaf sample which did not show a decrease in carbohydrate content that might be attributed to the wilting treatment was taken on July 14, 1944, when a maximum temperature of 100° F. was recorded.

On the average, the samples of stem bark showed a very slightly smaller total carbohydrate content in the wilted plants as compared with the checks. In many cases, however, a somewhat higher content was found in the bark of the wilted plants, indicating that the reduction found to have occurred in the carbohydrate content of the leaves did not extend to the bark of the lower stem. The average for all analyses in table 17 shows a decrease of 8 percent in the bark of wilted plants that might be due to the wilt treatment.

Effects of High Temperature on Carbohydrate Content of Leaves and Stem Bark

Analyses of cotton leaves taken from plants on clear days in the summer in an unshaded greenhouse showed marked reductions in the total carbohydrate content as compared with samples from similar plants kept outdoors. Under these conditions, the temperature in the greenhouse was usually 10 to 15 degrees higher than comparable readings outdoors and the samples were taken on days when the maximum greenhouse temperature was about 108° F. In the tests made during the spring of 1945, the high-temperature plants were kept in a partially closed greenhouse where the temperature remained between 100° and 110° F. with bright sunshine. These results were compared with those from other plants of

Table 17. Effect of wilting on carbohydrate content of leaves and stem bark of cotton plants.

Sample taken		Wilting treatment	Percent total carbohydrates			
			Leaves		Stem bark	
Date	Hour C. S. T.		Check	Wilted	Check	Wilted
		Planted 4/6/44, 4-gal. soil, 2 plants per treatment				
7/10/44	3 PM	Wilted once a day for 5 days	3.6	2.1	12.4	7.4
7/10/44	3 PM	Wilted continuously for 5 days	3.6	1.8	12.4	12.1
		Planted 4/6/44, 4-gal. soil, 2 plants per treatment				
7/17/44	4 PM	Wilted continuously for 3 days	7.6	1.2	11.2	8.0
		Planted 4/5/44, 2-gal. sand, 3 plants per treatment				
7/14/44	3 PM	Wilted 3 days (high daily T.)	2.2	2.6	9.4	9.2
		Planted 4/5/44, 2-gal. sand, 3 plants per treatment				
7/21/44	3 PM	Wilted 3 days (high daily T.)	3.6	0.0	4.4	6.0
		Planted 6/12/44, 1-gal. soil, 6 plants per treatment				
7/18/44	4 PM	Wilted 1 day	9.1	5.3	11.1	11.4
7/20/44	3 PM	Wilted 2 days	....	1.9	....	10.9
7/22/44	4 PM	Wilted 4 days	7.7	3.9	12.4	9.3
		Planted 4/5/44, 2-gal. sand, 2 plants per treatment				
8/11/44	8 AM	Wilted 4 days	2.7	1.1	9.0	12.2
		Planted 4/5/44, 2-gal. sand, 2 plants per treatment				
8/14/44	4 PM	Wilted 3 days	4.1	1.7	12.8	11.9
		Planted 4/5/44, 2-gal. sand, 3 plants per treatment				
8/21/44	8 AM	Wilted 5 days	1.9	1.1	9.8	13.2
		Planted 4/6/44, 4-gal. soil, 2 plants per treatment				
8/25/44	3 PM	Wilted 4 days	6.6	1.7	17.1	11.9
9/4/44	9 AM	Wilted 8 days	1.4	1.7	8.0	10.1
		Planted 6/12/44, 1-gal. soil, 4 plants per treatment				
9/4/44	10 AM	Wilted in greenhouse since 7/25 (mostly cloudy days)	3.4	1.6	9.5	6.6
		Planted 4/5/44, 2-gal. sand, 4 plants per treatment				
9/11/44	4 PM	Wilted 2 days	6.1	3.7	....	....
9/12/44	8 AM	Wilted 2 days	5.4	2.1	9.7	6.2

the same lot that were kept in a well-ventilated greenhouse in which the temperature rarely exceeded 85° to 90° F.

In most cases where the plants were kept under high-temperature conditions for several days (summer 1944), a decrease was found in the carbohydrate content of the leaves and stem bark (table 18). Additional data on the effects of relatively brief periods of high temperature on the relative increase in carbohydrate content of cotton leaves during the forenoon are shown in table 19. These data show a higher content in leaves from plants in a ventilated greenhouse than in those from comparable plants in the high-temperature greenhouse. The increase in carbohydrate content during the day under high-temperature conditions was less in the older plants (4-gal. soil cultures) that were nearing maturity than in the younger sand-culture plants. In this table, it may be seen that the carbohydrates in the soil-plant leaves were somewhat more than doubled during the forenoon on clear days under normal greenhouse temperatures. At the same time, similar leaves from plants in the high-temperature greenhouse showed only a 44 percent increase over the carbohydrate content found in the morning samples. With the sand-culture plants, the leaves from check plants increased 83 percent and those under high temperature increased 68 percent in carbohydrate content during the forenoon. In the case of both soil- and sand-grown plants, the younger leaves (near top of plant) appeared to be inhibited in carbohydrate accumulation under high-temperature conditions to a lesser degree than the older leaves (farther down the stem).

Table 18. Effect of high daily temperature for an extended period on total carbohydrate content of leaves and stem bark of cotton plants.

Sample taken		Treatment	Percent total carbohydrates			
			Leaves		Stem bark	
Date	Hour C. S. T.		Check	High T.	Check	High T.
Planted 6/26/44, 4-gal. soil, 2 plants per treatment						
9/15/44	4 PM	In greenhouse after 8/23	11.5	3.4	13.3	9.8
Planted 6/24/44, 2-gal. sand, 2 plants per treatment						
9/15/44	4 PM	In greenhouse after 8/23	6.1	3.9	12.7	5.5
Planted 7/5/44, 1-gal. soil, 2 plants per treatment						
9/15/44	4 PM	In greenhouse after 8/23	10.8	3.8	10.4	11.8
Planted 6/26/44, 4-gal. soil, 1 plant per treatment						
9/25/44	4 PM	In greenhouse after 9/21	3.9	1.1	6.5	4.8
		Average, all tests	8.1	3.1	10.7	8.0
		Percent of checks	....	38	....	75

Table 19. Total carbohydrate content of cotton leaves[1] following exposure to high *temperatures in a partly closed greenhouse for a few hours.*

Plants and samples		Sample taken		Percent total carbohydrates	
		Date 1945	Hour C. S. T.	Check[2]	High T.
Plants in Soil					
Planted 12/5/44, 4-gal. soil, 3 plants per treatment, 2 leaves per plant per sample		3/9	9 AM	5.8	5.3
		3/9	3 PM	9.5	5.0
Planted 12/5/44, 4-gal. soil, 6 plants per treatment, 1 leaf per plant per sample	Upper leaves	3/22	9 AM	4.9	4.5
		3/22	1 PM	7.7	8.5
	Middle leaves	3/22	9 AM	1.5	1.9
		3/22	1 PM	2.0	4.0
	Lower leaves	3/22	9 AM	0.6	0.8
		3/22	1 PM	2.9	0.7
	Upper leaves	3/26	8 AM	2.6	4.0
		3/26	1 PM	9.2	5.6
	Middle fruiting branch	4/2	8 AM	3.1	2.8
		4/2	1 PM	8.5	5.0
	Middle leaves	4/2	8 AM	4.8	5.6
		4/2	1 PM	7.5	7.3
	Average, morning samples			3.3	3.6
	Average, afternoon samples			6.8	5.2
	Increase during day—percent			106	44
Plants in Sand					
Planted 1/5/45, 2-gal. sand, 4 plants per treatment, 1 leaf per plant per sample	Upper leaves	4/2	8 AM	5.0	3.7
		4/2	1 PM	8.2	8.8
	Middle leaves	4/2	8 AM	3.4	1.6
		4/2	1 PM	5.8	3.2
	Upper leaves	4/4	9 AM	3.2	4.9
		4/4	2 PM	6.8	5.9
	Middle leaves	4/4	9 AM	2.5	3.6
		4/4	2 PM	2.8	3.5
	Middle leaves	4/6	8 AM	3.4	3.1
		4/6	2 PM	8.6	7.1
	Average, morning samples			3.5	3.4
	Average, afternoon samples			6.4	5.7
	Increase during day—percent			83	68

[1]Stem leaves except as noted.
[2]Plants in well-ventilated greenhouse.

Increase During the Day in Carbohydrate Content of Leaves of Different Ages

In view of the high rates of shedding that are usually observed in cotton plants that have already set a number of bolls and that are approaching maturity (late in the fruiting period), a series of carbohydrate analyses was planned which might indicate the relative photosynthetic activity of the old and young leaves on the same plant at this stage of growth. In order to compare leaves of different ages, those near the top of the stem were compared with lower stem leaves as to the increase in amount of carbohydrate materials accumulated during the forenoon. Table 20 shows the results of fourteen comparisons between upper (young) and middle (older) leaves. Considering all samples, the carbohydrate content of the upper leaves was 37 percent greater in the afternoon than in the morning while the content of middle leaves on the same plants increased 7 percent during the same period. Since the leaves compared were from the same plants and under similar environmental conditions, it would appear that the greater age of the middle stem leaves was an important factor in the apparently lower photosynthetic activity. It is of interest also to note in table 20 that the leaves from the oldest plants, particularly those in soil culture which had begun to show yellowing of the foliage, were found to have a high carbohydrate content and these plants translocated only a small part of the carbohydrates from the leaves during the night.

The carbohydrate accumulation in the soil-grown plants (table 20) occurred shortly after most of the shedding of the last small bolls had taken place, at the time the first bolls were starting to open. Similar accumulation of carbohydrates was also found in younger plants (early summer 1945) in soil culture that were in a stunted condition and had ceased growth about the time the first blooms opened. The leaves of these relatively young plants showed a carbohydrate content around 11 percent both in the morning and afternoon. This accumulation of large amounts of carbohydrate material in the leaves of the old soil-plants may have been due, at least in part, to the depletion of nitrogen from the soil. However, a somewhat similar condition was found in the sand-culture plants (May 2 samples, table 20) which were still receiving the usual daily applications of nutrient solution. In this connection, samples taken on May 24 of upper leaves from plants of this same sand-culture series, which were placed outdoors on May 8 and had dormant terminal buds since that time, showed a very low carbohydrate content both in the morning (3.2 percent) and afternoon (3.5 percent). At that time (May 24) about half of the bolls on these plants had opened and no new vegetative growth was apparent. This would indicate an unusually low photosynthetic activity in the leaves of these old plants. By June 15, small new leaves had developed on these plants as secondary growth and these leaves showed a carbohydrate content of 4.6 percent in the morning and 8.0 percent in the afternoon.

Table 20. Total carbohydrate content of upper and middle stem leaves of cotton plants, in the morning and afternoon.

Plants and samples		Sample taken		Percent total carbohydrates	
		Date 1945	Hour C. S. T.	Upper leaves	Middle leaves
Planted 12/5/44, 3-gal. soil, 6 plants, 1 leaf per plant per sample. (Plants yellowish)		3/27	8 AM	14.2	8.9
		3/27	1 PM	18.5	11.6
		4/13	8 AM	8.3	8.3
		4/13	3 PM	8.0	8.0
Planted 12/5/44, 4-gal. soil, 6 plants per treatment, 1 leaf per plant per sample	Plants green	3/22	9 AM	4.9	1.5
		3/22	1 PM	7.7	2.0
	Plants green	4/3	8 AM	5.3	5.7
		4/3	3 PM	6.9	7.0
	Plants green	4/6	8 AM	5.6	4.7
		4/6	2 PM	11.2	6.8
	Plants yellowish	4/6	8 AM	8.8	6.9
		4/6	2 PM	17.8	6.5
	Plants green	4/13	8 AM	12.4	8.6
		4/13	2 PM	15.7	10.0
	Plants yellowish	4/13	8 AM	19.3	16.0
		4/13	2 PM	21.0	20.9
Planted 1/5/45, 2-gal. sand, 4 plants per treatment, 1 leaf per plant per sample, in greenhouse		4/2	8 AM	5.0	3.4
		4/2	1 PM	8.8	5.8
		4/4	9 AM	3.2	2.5
		4/4	2 PM	6.8	2.8
		4/23	9 AM	3.7	4.9
		4/23	3 PM	6.5	3.6
		5/2	8 AM	5.5	6.2
		5/2	4 PM	6.4	7.8
Planted 1/5/45, 2-gal. sand, 4 plants per treatment, 1 leaf per plant per sample; plants outdoors		4/23	9 AM	6.8	6.5
		4/23	3 PM	7.7	5.9
		5/2	8 AM	9.5	9.1
		5/2	4 PM	10.6	9.7
	Average, morning samples			8.0	7.2
	Average, afternoon samples			11.0	7.7
	Increase during day—percent			37	7

Analyses of Leaves from Plants Grown in the Greenhouse During the Summer

Leaves and stem bark of plants kept in the unshaded greenhouse in the summer for the duration of the fruiting period showed a medium to high carbohydrate content in both morning and afternoon samples, in the few samples taken during the 1944 test. These samples were taken near the time of harvest when the oldest bolls were starting to open.

Analyses of Other Parts of the Plant in Relation to Shedding

Stem bark vs. root bark. In case of some of the early analyses in this work, total carbohydrate determinations were made of both lower-stem bark and root bark. The carbohydrates in these two materials were found to be quite similar quantitatively and they were also found to vary to practically the same extent following shading treatments of six-days duration. Consequently, the taking of root-bark samples was omitted from this work and analyses were made only of the bark on the lower stem, 5 to 7 inches above the soil line.

Woody portion of stem. Preliminary analyses of the central cylinder (wood) of the lower stem and taproot of cotton plants used in these experiments showed the carbohydrates in this part of the plant to remain relatively stable during the few-days shading treatments that were applied to induce shedding. These analyses were therefore discontinued in favor of the stem-bark data which were found to undergo changes in carbohydrate content much more rapidly than the woody parts of the stem.

Young bolls and bracts. Many analyses of young bolls, from a few days after flowering up to formation of fibers strong enough to interfere with cutting by a knife, were made to ascertain any possible correlation between carbohydrate contents of the boll and shedding tendencies. Shading for a few days was found to cause distinct reductions in the carbohydrate content of the bolls in many instances. With wilted plants, no significant differences were found. It was also difficult at times to compare bolls of the same age on wilted and nonwilted plants, due to the tendency of those on the wilted plants to ripen prematurely and thereby resemble physiologically bolls on the check plants that were much older. In general, the variations in carbohydrate content of the young bolls were not as consistent, in relation to the shedding responses to the treatments, as the variations in carbohydrate content of the leaves. These results indicate that the amount of carbohydrate synthesized by the plant and available for the competitive utilization throughout the plant is one of the most important internal conditions concerned in shedding.

Young bolls (about 5 days after blossoming) that were shed from full-grown nontreated cotton plants were found to have a considerably lower total carbohydrate content (6.4 percent) than comparable bolls (11.0 percent) that remained on the same plants. Similarly low carbohydrate contents were found in small bolls that were caused to be shed by shading of the plants. In one test, no difference was found between the carbohydrate contents of small bolls that were shed from wilted plants as compared with those picked from nonwilted (check) plants; while at another time the shed bolls showed only a little over one-half the amount (3.5 percent) present in unshed bolls. At the same time, bracts were removed from half-grown bolls (on both check and wilted plants) that were not shed but no difference was found in the carbohydrate content of these bracts (3.7 and 3.9 percent, respectively). The carbohydrate content of the interior of these bolls was 24.8 and 25.2 percent, respectively.

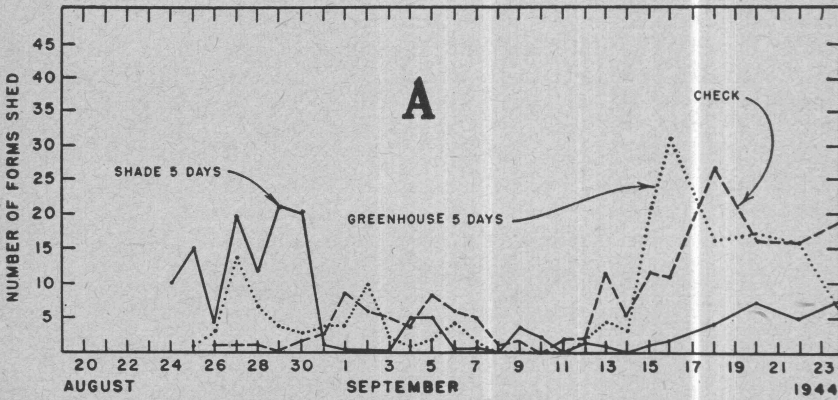
DISCUSSION

In this study, variations in the amount of light in the environment of the cotton plant have been associated with profound differences in fruiting behavior. In most cases, marked differences in vegetative growth have accompanied changes in fruiting. The effects on fruiting processes have been seen in various ways but chiefly in the number of fruiting forms developed on the plant and in the relative number of forms that have been shed prior to maturation of the bolls. Evidence is presented which indicates that periods of cloudy weather during the fruiting period constitute a hazard in the production of the cotton crop. In many instances, varietal differences have been found among the responses of cotton to these variations in the light factor. Recognition of this inherent quality by the plant breeder may lead to the improvement of commercial strains so that they may be better adapted to specific growing conditions.

Of the three factors (light, drought and heat) that have been studied as causes of shedding in cotton, light has appeared the most important, under the conditions of this work. Considering the large amount of shedding induced and the apparent lack of serious concurrent damage to other parts of the plant (such as loss of leaves), periods of low light intensity appear to be a natural and highly effective cause of shedding. In comparison with high-temperature treatments, shedding brought about by low light intensity has been more sudden and of greater intensity (fig. 22-A). High shedding rates, similar to those found under poor light conditions, have been caused by wilting (fig. 22-B), although plants that have been wilted severely enough to cause considerable shedding usually show a certain amount of leaf damage that was not apparent in shading experiments. In Nigeria, Thornton (52) found that shedding during the dry season was accompanied by loss of leaves while no loss of foliage was associated with shedding during the wet period. It is particularly significant, too, that most of the treatments and conditions that involved impaired light conditions (shading, fall and winter conditions, close spacing, and shortened day length) resulted similarly in increased shedding rates and impaired fruiting capacity of the plant.

As shown by carbohydrate analyses, particularly of leaf material, a possible relationship is indicated between the three common causes for shedding studied here—light, drought, and high temperature—and the synthesis or utilization of carbohydrates by the plant. The carbohydrate content of leaves, stem bark and root bark was found to be depleted when the plants were kept under low light intensities for a few days. Wilting was also found to lower the photosynthetic ability of cotton leaves, as shown by the relatively small increase in the carbohydrate content of leaves on wilted plants. The apparent (often slight) increase sometimes found in the carbohydrate content of the stem bark after a period of wilting may have been due to interference with sugar movement, especially since wilting of greenhouse plants appeared to cause a measureable decrease in diameter of the stem.

Although the carbohydrate content of cotton leaves was found in some cases to increase during the first hours of exposure to abnormally high temperatures, considerable depletion of carbohydrates was noted in the leaves, and to a lesser extent in the stem-bark, of plants that had been



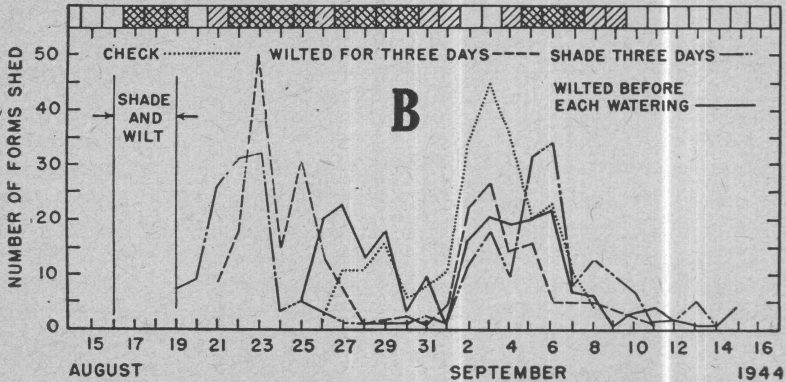


Fig. 22. Comparisons of shedding curves following shade, high temperature, and wilting treatments. A. Three curves each representing 8 plants in sand culture. Note the increase in early shedding due to the 5-day shade and high temperature (greenhouse) treatments, both applied on August 22-27. B. Each of the four curves represents the average of 7 plants in soil. Each of the three treatments (wilted for 3 days, shaded for 3 days, and wilted for a few hours between each watering after August 16) shows a high rate of shedding before the check plants (dotted line) had shed any forms.

kept in an unshaded greenhouse for several days during the summer (table 18). In this connection it should be noted that only moderate increases in shedding rates due to high temperatures were found, in comparison with the effects of shade or wilting. Likewise, the reduction in the fruiting capacity of high-temperature plants, in comparison with lower-temperature controls, has not been especially severe. Possibly, high temperatures may promote more rapid vegetative growth and also a more rapid respiratory rate, as suggested by Wadleigh (55), which could result in a severe drain on the carbohydrate reserves and which may have been responsible for the more severe shedding and smaller bolls reported here. It has been shown by Armstrong and Albert (5) that removal of leaves from the fruiting branch also reduces the size of cotton bolls.

Under field conditions, it would be difficult to differentiate between the effects of cloudiness and those of too high rainfall upon shedding. The curves presented by Harland (26) for cotton in the West Indies show that heavy shedding took place during and following heavy rainfall in late October and early November and he suggested that root asphyxiation may have caused the peaks in the shedding curve. On the other hand, Harland noted that flower-bud shedding occurred with plants under controlled moisture conditions in containers at the same time as with plants under field conditions. Experimental flooding of soil, however, has not produced sufficiently intense shedding in most cases to support adequately the soil-saturation theory. In cases where increased shedding rates have been obtained by flooding, most of the shedding has occurred in the young square stage (2, 43). In this connection, it should be remembered that high rainfall does not necessarily mean excessive cloudiness, nor vice versa. For example, Canney (11) has pointed out that the northeast coast of Brazil has four times as much rainfall annually as the coastal region of Portugese East Africa where the "annual cloudiness" is twice as much as in northeast Brazil. For practical purposes, however, it is certain that cotton in areas of fairly high rainfall during the growing season is subjected to many more fluctuations in light conditions than would be encountered in areas of low rainfall.

In the case of high temperatures, it may not always be possible to differentiate between heat effects and those of wilting, since water loss from the plant is much greater at unusually high temperatures than under normal conditions. Although wilting is not apparent, a plant under high temperature conditions may suffer effects similar to those obtained from visible wilting, due to the water-stress within the plant. Hastings (27) has stated that the unfavorable effect of high temperatures is aggravated by low soil-moisture contents. Schneider et al. (46) found with apple leaves that a marked reduction in photosynthesis and transpiration, together with an increase in respiration, took place before wilting was evident. Heinicke and Childers (31), working with apple leaves, found a gradual drying of the soil to be accompanied by an appreciable reduction in the rate of transpiration and of photosynthesis. Alekseev (3) reported a decrease in CO_2 absorption by apple leaves when the fresh

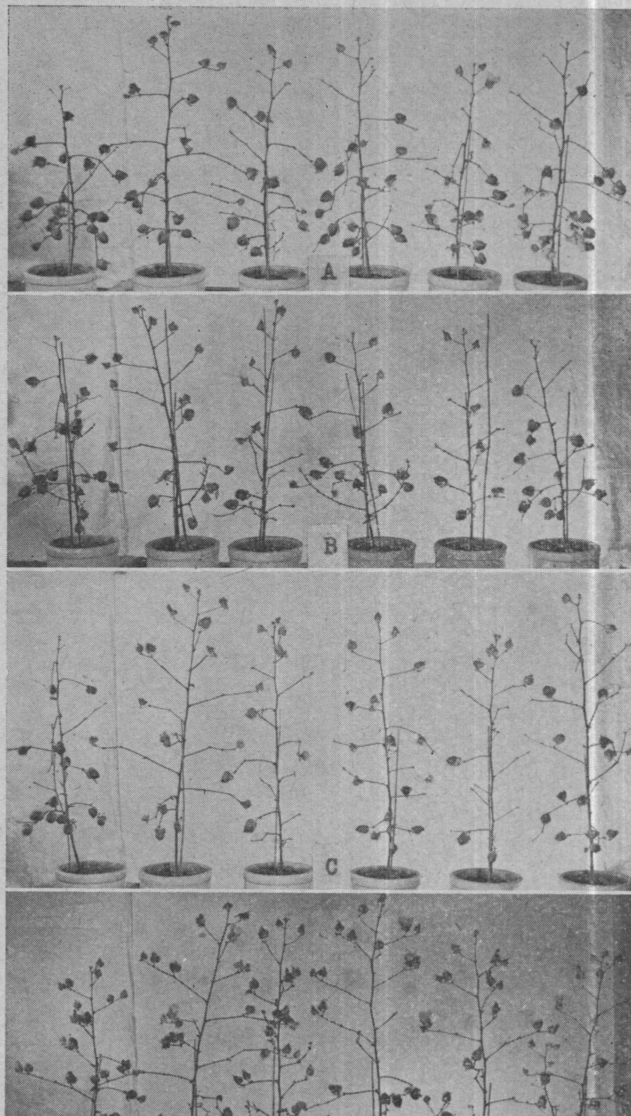


Fig. 23. Defoliated cotton plants (spring series in greenhouse, 1944) showing differences in growth and fruiting between the following treatments: A. Check, B. Short day (8 A. M. to 3 P. M.), C. Close-spaced, D. Shaded 4 days early in fruiting period. Six varieties are shown in each series, from left to right: Stoneville 2B, Rogers Acala, A. D. Mebane Estate, Deltapine 14, Qualla, and Half and Half. Note the better set of bolls in checks than in any of the treatments. Also, the shade resulted in larger plants (D) with many more young forms at time of harvest.

weight of the leaf was reduced below 80 percent of the maximum moisture content.

The well-known tendency for cotton plants to shed many young bolls late in the season, usually after a crop of bolls has been set and many of the bolls are fairly mature, deserves special mention in connection with these studies. At this time, the maturing bolls probably make a heavy demand for available sugars. As shown by the carbohydrate analyses in table 19, older leaves appear to be less active in carbohydrate manufacture than young leaves. A decrease in the total carbohydrates in tobacco was found by Dennison (14) as the leaves became older. Since there is usually but little leaf growth after the plant has set a fair load of bolls, most of the foliage has become well advanced in age by the time this late-season shedding becomes prominent. Evidence is also shown in table 19 that photosynthesis in the older cotton leaves was more likely to be impaired by high temperature than was the case in younger leaves, as shown by the smaller carbohydrate accumulations in old leaves during the day. As may be seen in figs. 5-C, 16-A, and 19, sharp peaks of shedding may not always occur as the plants reach maturity. Apparently, cotton plants do become more sensitive to external shedding stimuli at this time, however, (figs. 3-A, 3-B, and 5-B).

As commonly noted, young bolls, a few days after flowering, are more susceptible to shedding than fruiting forms in earlier or later stages of development. However, an increase in the severity or length of a treatment that induces shedding has been found to result in abscission both of younger (squares) and older cotton forms (half-grown bolls). When outdoor plants in the summer were placed in the laboratory, a relatively large number of squares was shed before the peak of shedding of the small squares was reached (table 9). In some of the greenhouse experiments during the winter, however, considerable shedding of the smallest squares (up to 5 mm.) took place along with the loss of the small bolls. At the same time, a smaller number of older squares was shed. These results indicate further a common cause for shedding of forms of all ages, from the smallest square up to the partially matured boll. Bailey and Trought (6) expressed the opinion that those conditions which caused shedding of the smallest flower buds induced buds of other sizes to shed also.

It has been noted that the most damaging results, insofar as final set of bolls is concerned, followed the shading and other low-light-intensity treatments that were applied fairly early in the fruiting period (table 8). In the case of this and similar experiments, however, the treatments have been late enough to cause shedding of large squares and at least a few young bolls. As a result, it seems that shedding of the larger fruiting forms (half-grown squares or older) may be more devastating to the fruiting activities of the cotton plant than shedding of small squares. As stated previously, during certain experiments under fall or winter greenhouse conditions excessive small-square shedding had been recorded but the yield of bolls from these plants was equally as good as from plants in comparable experiments where shedding of these smallest forms was not so prominent. This conclusion is in keeping with results of certain studies in Mississippi where Hamner (25) found no reduction in yield from removal of small squares (about 3 days old) but where Dunnam et al. (19) obtained a reduction in yield of cotton in proportion to the percentage of larger squares (6 to 14 days old) removed. Possibly the stimulus towards increased vegetative growth is more intense following removal of large fruiting forms than in the case of the smallest squares.

From a physiological standpoint, shedding caused by some environmental factor may not be at all analogous to the loss of fruiting forms by hand removal or through insect injury. In case of the former, the shedding occurs as a result of a condition within the plant which does not allow more fruit to be set at that time. Favorable conditions for fruiting would have to be restored before normal fruiting could proceed. In the case of mechanical removal or insect injury, on the other hand, the general condition of the plant would be as favorable for fruiting as it was before the loss of the forms. The plant would be able, therefore, to proceed immediately with the development of the remaining forms and any change in fruiting tendencies might not be at all serious. Excessive shedding after a period of cloudy weather is a definite indication that the plant is physiologically unable at that time to set and maintain additional fruit and its growth activities can be expected to be predominantly vegetative. A surge of vegetative growth might be initiated at this time and maintained for the remainder of the season to the detriment of the fruiting processes.

It has been observed throughout this work that shedding does not always occur the same number of days after the causative treatment. Shedding can be induced more easily with large vegetative plants, such as those in the greenhouse in the winter, than with outdoor plants in the summer. This may be due to differences in carbohydrate reserves within the plant. As may be recalled, shedding from either low light intensity or wilting has occurred only after one or two days of the treatment. This allowed adequate time for certain food reserves to be depleted. In all probability, one or more days would be required for the abscission layer to form and for the adjacent cells to separate, following the shedding stimulus. Lloyd (38) caused small bolls to shed within 24 hours by mechanical injury and "the more drastic the operation, the more rapid the response." In the case of bolls that were shed when about 14 days old, Lloyd allowed "a true response period of six to ten days as the approximate limits of requirement." The time required for shedding, following application of the stimulus, may also depend upon the age of the plant since Ewing (23) noted that the "period of persistence" for bolls shed early in the season was from 9 to 16 days after flowering whereas late in the season most of the bolls were shed about 4 to 6 days after flowering.

High carbohydrate contents of leaves and stems do not always prevent shedding from taking place, however, as shown by the relatively high contents of the stem-bark of plants following periods of wilting, by the fairly high levels of carbohydrates in cotton leaves under summer greenhouse conditions and by the apparent reserve in older plants that show late-season shedding. In the latter case, the carbohydrates may be in a form unsuitable for translocation, or the effects of drought, high temperature, or age of vegetative organs may result in interference with the translocation process. Any factor that tends to inhibit a constant supply of soluble carbohydrates to the young bolls would most likely cause increases in shedding rates. The food requirements of other parts of the plant, such as leaves, stems, and roots, may also play an important part in determining the proportional amount of carbohydrates that are made available to the bolls or squares. It is quite possible, also, that the older bolls (past the shedding stage) may compete for available sugars more successfully than the younger bolls.

Some of the most serious effects, as far as shedding and reduction in number of bolls per plant are concerned, have been obtained in cases where a stimulus to shedding has been followed by another after several days. Evidence of this can be seen in table 6 and in figs. 13 and 22-A. Such recurrence of stimuli for shedding undoubtedly occur frequently under field conditions in the periodic occurrence of cloudy weather, dry periods between rains, or a few unusually hot days separated by cooler periods. On the other extreme, the least noticeable effects upon shedding and fruiting have been found after a single moderate treatment has been followed by favorable environmental conditions for the remainder of the fruiting period. In some cases, even a beneficial effect on fruiting has been recorded following a single mild shade treatment; these effects may be similar to those noted by Eaton (21) following removal by hand of the first squares. The results obtained here, however, involve for the most part only one or two shading treatments during the life of the plant. In most crop environments, poor light conditions with low intensities undoubtedly may occur much more frequently and with equally damaging results each time.

Working with cotton plants in a shaded greenhouse during the summer, Wadleigh (55) concluded: "after a plant had set a number of bolls sufficient to deplete its nitrogenous reserves, all subsequently formed young bolls abscised" and this was followed by abscission of young squares and abortion of the terminal buds on fruiting branches. In the studies reported here, similar cases of high shedding rates during the latter part of the fruiting period have been recorded for plants in the summer outdoors, both in sand that was supplied constantly with a high-nitrogen nutrient solution and in soil from which the available nitrogen must have been more or less exhausted. When the nitrogen content of the nutrient solution was changed (from low to high or from high to low), near the middle of the fruiting period, no marked changes in the shedding curves were noted. Further growth and fruiting of the plants, however, took place in proportion to the amount of nitrogen supplied following the shift in solutions, indicating absorption of nitrogen by the roots in proportion to the amount available. The increased yields that were obtained (table 14) by increasing the amount of nitrogen supplied were accompanied by renewed vegetative growth and development of new foliage which may have made possible the increase in number of bolls per plant. It is of interest to note that, in spite of the sudden change in amount of nitrogen supplied, the final yield of bolls varied directly with the amount of nitrogen and, even with the considerable differences found in the amount of fruiting and size of plants, the final percentage of bolls set was remarkably alike for all treatments.

In these studies, certain varieties of cotton, notably Stoneville 2B, Half and Half, Coker 4-in-1, Washington, Deltapine 14, and Roldo Rowden have been found to be relatively less sensitive to unfavorable light conditions imposed in various ways than certain other varieties such as Rogers Acala, A. D. Mebane Estate, Qualla, and Lone Star. These varieties have maintained higher fruiting capacities (indicated by number of bolls per plant and weight of these bolls) when performance under winter growing conditions was compared with summer productiveness. Also, under shade treatment, Stoneville 2B was found to show better fruiting tendencies than Rogers Acala. Similar differences were noted between these same varieties, in regard to close-spacing and high-temperature treatments, and variations in the total number of hours of sunshine per day but the data in these cases did not show significant differences in interactions between treatments and varieties. However, in many cases the averaged data for a group of plants have shown differences in favor of the first group of varieties mentioned above. In many cases, the treatments used caused considerably more variation between individual plants than occurred among the checks. Therefore statistical significance could not be demonstrated. No significant differences were found in the reaction of ten different cotton varieties (table 11, 5th part) to a single period of wilting for five days, under greenhouse conditions; which might indicate less inherent difference between these varieties in regard to drought resistance than in regard to ability to withstand unfavorable light conditions. As a result of these tests, it seems quite likely that the popularity among growers of some of the varieties, either old or new, may be due to the ability of the strain to withstand certain unfavorable influences of poor light in the environment, that may occur under field conditions much more frequently than the grower may suspect.

In view of the evidence presented, it seems likely that weather conditions frequently may affect the amount of sunlight available to cotton plants under field conditions in many cotton-growing areas to the extent that excessive shedding may occur. Harmful shedding would most likely occur in dense stands of rapidly growing plants such as often occur in fertile soil and favorable moisture conditions. When these hazards are combined with those of drought, and when consideration is given to the danger of shedding from high temperatures, it can be easily imagined that few crops of cotton escape strong shedding stimuli, even before a fair crop of bolls has been set. Cotton that has received a favorable amount of rainfall would undoubtedly suffer at times from poor light conditions due to cloudy weather. Also, dry-land cotton in many regions must often feel the effects of drought. Fields under irrigation are likely to lie in areas of high daily temperatures. Optimum conditions for cotton fruiting, therefore, may be obtained only rarely under field conditions. The use of varieties that withstand unfavorable environments to the highest degree would appear most desirable and profitable as insurance against low yields from these nonpreventable circumstances. The importance of favorable light conditions for cotton, presuming that irrigated regions usually have an abundance of sunshine, is implied in the statement by Todd (53): "Cotton was certainly at first a rain crop . . . . .; but the quantity of cotton grown under irrigation in every part of the world is now very large. Indeed, it appears that the best growing conditions can only be secured under irrigation."

It has been estimated (45) that one more good boll on every stalk of cotton in four southwestern states, Texas, Oklahoma, Arkansas, and Louisiana, would increase the annual yield of lint from this area by 900,000 bales. This result might be obtained by planting more extensively the higher-yielding cotton varieties that are least sensitive to certain unfavorable environmental conditions and which have desirable fruiting capacities. In the light of some of the experimental work herein reported, it would seem possible to improve materially the yield of cotton under Texas conditions by planting varieties that are best adapted to the particular area in which they are grown. It appears important to consider the effects of certain factors, especially variations in sunlight intensity associated with changes in weather, in selecting varieties of cotton best adapted to a given region.

SUMMARY

1. The cotton plant has been found sensitive to variations in amount of light as shown by vegetative growth and amount of fruit set under different light conditions.

2. Periods of low light intensity or short-day periods of full sunlight have resulted in impairment of the fruiting capacity of the plant and an increase in vegetative growth.

3. These effects of light on fruiting and shedding in cotton have appeared more important than those of drought or high temporature.

4. Inferior fruiting and, in most cases, increased rates of shedding have been found associated with fall-winter environmental conditions, shading and close-spacing of plants, and reduction in number of hours of sunshine per day.

5. Periods of cloudy weather during the fruiting period or treatments

involving similarly low light intensities for a few days have been followed by increased rates of shedding of fruiting forms.

6. These variations in the amount of light available to the plant have been associated more closely with the relative number of bolls maintained to maturity than with the formation of flower buds (photoperiodism).

7. Certain varieties of cotton, such as Stoneville 2B, Coker 4-in-1, Deltapine 14, Half and Half, Roldo Rowden, and Washington, were found, in general, to be less sensitive to unfavorable variations in light conditions than certain other varieties tested, such as Qualla, A. D. Mebane Estate, Rogers Acala, and Lone Star.

8. Wilting of cotton plants continuously for a few days at a time was found to cause excessive shedding. However, brief periods of wilting (up to one or two days), although occurring frequently, resulted only in curtailment of vegetative growth, fewer and smaller bolls per plant, and usually no marked increase in shedding rates.

9. The addition of nitrogen to jars of soil in which cotton plants were growing resulted in increases in yield of bolls when the soil moisture content was adequate. With frequent wilting, or with soil of a continuously low moisture content, however, these benefits from extra nitrogen were not obtained. In most cases, no marked differences in shedding rates were found between high- and low-nitrogen plants as a result of water-stress treatments.

10. Certain treatments involving excessively high soil moisture resulted in increased shedding of cotton forms, especially when poor drainage was provided in jars of soil. Often, the high shedding rate was preceded by wilting of the leaves and in some cases it was followed by death of the plant.

11. High shedding rates and decreases in weight of bolls per plant were also found associated with high temperatures (around 100° F. or above), either during extended periods of high daily temperatures or following briefer periods of exposure to such conditions.

12. Under outdoor conditions in the summer, the number of bolls per plant varied in proportion to the amount of nitrogen supplied. Consistent increases in fruiting, however, were not obtained from additional nitrogen applications under fall-winter conditions in the greenhouse.

13. Differences in fruiting resulting from the addition of extra phosphorus or potassium (above adequate, basic amounts) in sand culture were usually small and the shedding rates were found to remain fairly uniform under conditions of widely different nutrient (N, P, and K) levels. The best fruiting was usually obtained with properly balanced nutrients.

14. Certain treatments of the stem of cotton squares or flowers with "chemical hormones" prevented formation of the abscission layer but did not prevent abortion of the young boll.

15. Wetting of open flowers twice daily with an atomizer caused only slight increases in the percentage of young bolls shed.

16. No outstanding impairment of fruiting activity was caused by removal of bracts from squares, topping of plants, removal of leaves from fruiting arms, and covering of squares with such materials as black cloth, tinfoil, or cellophane.

17. Chemical analyses of the leaves (and, in some cases, stem bark) from plants that were subjected to conditions of low light intensity, drought, or high temperature have shown a low carbohydrate content or a low rate of photosynthesis to be associated with these shedding-inducing treatments.

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